INSTITUTION

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PROCEEDINGS.

1877.

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1877.

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George Stephenson, ...	(*deceased* 1848).
Robert Stephenson, F.R.S., ...	(*deceased* 1859).

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COUNCIL.

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Walter May, ...	Birmingham.
John Penn, Jun., ...	London.
William Richardson, ...	Oldham.
John Robinson, ...	Manchester.

TREASURER.

Henry Edmunds.

SECRETARY.

William P. Marshall.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

1877.

MEMBERS.

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.
1874. Abernethy, James, 4 Delahay Street, Westminster, S.W.
1876. Adams, Henry, 9 George Lane, Eastcheap, London, E.C.
1875. Adams, Thomas, Ant and Bee Works, West Gorton, Manchester.
1848. Adams, William Alexander, Walford Manor, near Shrewsbury.
1859. Adamson, Daniel, Engineering Works, Hyde Junction, near Manchester; and The Towers, Didsbury, near Manchester.
1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester.
1861. Addenbrooke, George, Ashville Lillington, Leamington.
1851. Addison, John, 6 Delahay Street, Westminster, S.W.
1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.
1870. Alexander, Alfred, Messrs. Tangye Brothers', Cornwall Works, Soho, Birmingham.
1847. Allan, Alexander, Glen House, The Valley, Scarborough.
1875. Allan, George, Savile Street Engineering Works, Sheffield.
1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.
1870. Alley, John, Engineer and Contractor, Moscow.
1877. Alley, Stephen, Messrs. Alley and MacLellan, 33 Virginia Street, Glasgow.
1865. Alleyne, Sir John Gay Newton, Bart., Butterley Iron Works, Alfreton.
1872. Alliott, James Bingham, Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.
1876. Allport, Charles James, Littleover, Derby.

1871. Allport, Howard Aston, Bestwood Coal and Iron Co., Rob Roy Terrace, Nottingham.
1861. Amos, Charles Edwards, 5 Cedars Road, Clapham Common, London, S.W.
1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.
1876. Anderson, Henry John Card, Manager of Sugar Mills of the Viceroy of Egypt, Cairo, Egypt.
1856. Anderson, John, LL.D., F.R.S.E., 22 Victoria Road, Old Charlton, London, S.E.
1856. Anderson, William, Messrs. Eastons and Anderson, Erith Iron Works, Erith, London, S.E.
1858. Appleby, Charles Edward, 20 Great George Street, Westminster, S.W.
1867. Appleby, Charles James, Messrs. Appleby Brothers, Emerson Street, Southwark, London, S.E.
1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid.
1874. Archer, David, General Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.
1859. Armitage, William James, Farnley Iron Works, Leeds; and Southgate House, Southgate, Middlesex, N.
1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.
1863. Armstrong, John, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.
1857. Armstrong, Joseph, Locomotive Superintendent, Great Western Railway, Swindon.
1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.
1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.
1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.
1873. Arnold, David Nelson, Manager, Midland Wagon Works, Lander Street, Birmingham.
1857. Ashbury, James Lloyd, M.P., 66 Grosvenor Street, London, W.
1873. Ashbury, Thomas, Managing Director, Ashbury Railway Carriage and Iron Works, Openshaw, Manchester; and 215 Plymouth Grove, Manchester.
1877. Astbury, James, Smethwick Foundry, near Birmingham.
1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield.
1875. Atkinson, Edward, 134 Earl's Court Road, Kensington, London, S.W. (*Life Member.*)

1869. Austin, William Lawson, Messrs. Austin and Dodson, Cambria Steel and File Works, Arundel Street, Sheffield.

1869. Aveling, Thomas, Messrs. Aveling and Porter, Rochester.

1874. Ayton, Frederick, Messrs. Ayton and Co., Eagle Brewery, Bishopbriggs, Glasgow.

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley.

1865. Bailey, John, Messrs. Courtney Stephens and Bailey, Blackhall Place Iron Works, Dublin.

1860. Bailey, Samuel, Mining Engineer, Perry Pont House, Perry Barr, Birmingham.

1872. Bailly, Philimond, 37 Rue des Fripiers, Brussels.

1873. Baird, George, Messrs. Baird, Iron Works, St. Petersburg; and 5A Cork Street, Burlington Gardens, London, W.

1866. Baker, Samuel, Engine and Boiler Works, 22 Oil Street, Liverpool.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1877. Bale, Manfred Powis, 20 Budge Row, Cannon Street, London, E.C.

1870. Barber, Thomas, Mining Engineer, High Park Collieries, Eastwood, Nottinghamshire.

1870. Barclay, Arthur, 12 York Street, Covent Garden, London, W.C.

1860. Barker, Paul, Church Road, Yardley, near Birmingham.

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1866. Barnard, Clement, 4 Billiter Square, London, E.C.

1862. Barrow, Joseph, Messrs. Smith Beacock and Tannett's Works, Victoria Foundry, Leeds.

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury.

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W.

1862. Barton, Edward, Carnforth Hæmatite Iron Works, Carnforth.

1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Elm Tree Villa, Smallheath, Birmingham.

1877. Beale, William Phipson, 6 Stone Buildings, Lincoln's Inn, London, W.C.

1865. Beardshaw, Charles C., Baltic Steel Works, Sheffield.

1869. Beattie, William George, Locomotive and Carriage Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1859. Beck, Edward, Dallam Forge, Warrington; and Palmyra Square, Warrington. (*Life Member.*)

1873. Beck, William Henry, 139 Cannon Street, London, E.C.

1875. Beckwith, John Henry, Engineer to Messrs. W. and J. Galloway and Son Knott Mill Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester.

1865. Bell, Charles, Messrs. Palmer and Bell, Agricultural Engineers, Taganrog, South Russia; and 59 South Street, Greenwich, S.E.

1858. Bell, Isaac Lowthian, M.P., F.R.S., Clarence Iron Works, Middlesbrough; and Harlsey Hall, Northallerton.

1857. Bellhouse, Edward Taylor, Eagle Foundry and Iron Works, Hunt Street, Oxford Street, Manchester.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham.

1854. Bennett, Peter Duckworth, Spon Lane Iron Foundry, Westbromwich.

1877. Bennett, Thomas Oldham, Manager, Manchester Steel Screw Works, Bradford Mills, near Manchester.

1872. Bennett, William, Jun., 38 Sir Thomas' Buildings, Liverpool.

1875. Berry, Francis, Messrs. Francis Berry and Sons, Calderdale Iron Works, Sowerby Bridge.

1861. Bessemer, Henry, 4 Queen Street Place, New Cannon Street, London, E.C.; and Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Manor Hill, Birkenhead.

1874. Bewick, Thomas John, Mining Engineer, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W.; and Haydon Bridge, near Carlisle.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1861. Binns, Charles, Mining Engineer, Clay Cross, near Chesterfield.

1877. Birch, Robert William Peregrine, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1866. Birkbeck, John Addison, 112 Grange Road, Middlesbrough.

1847. Birley, Henry, Haigh Foundry, near Wigan.

1875. Bisset, William Harvey, Board of Trade Surveyor, St. Katharine Dock House, London, E.; and 18 Canonbury Park Square, London, N.

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1863. Boeddinghaus, Julius, Machine Works and Iron Foundry, Düsseldorf, Germany.

1872. Boistel, Georges, 11 Rue de Châteaudun, Paris.

1872. Bolton, Lt.-Colonel Francis John, 4 Broad Sanctuary, Westminster Abbey, Westminster, S.W.

1869. Borrie, John, New Exchange Buildings, Middlesbrough.

1862. Bouch, Thomas, 111 George Street, Edinburgh.

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes, Lancashire and Yorkshire Railway, Engineer's Office, Manchester. (*Life Member.*)

1869. Boyd, William, Wallsend Slipway Co., Wallsend, near Newcastle-on-Tyne.

1875. Braconnot, Capt. Carlos, Chief Director and Engineer of the Marine Arsenal, Correio Geral, Caixa 232, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1875. Bradley, Isaac, Ammunition Works, Mill Lane, Ward End, Birmingham.

1854. Bragge, William, Shirle Hill, Hamstead Road, Birmingham.

1875. Braithwaite, Richard Charles, Manager, Old Park Iron Works, Wednesbury.

1854. Bramwell, Frederick Joseph, F.R.S., 37 Great George Street, Westminster, S.W.

1868. Breeden, Joseph, Messrs. Breeden and Booth, 157 Cheapside, Birmingham.

1875. Broadbent, Thomas, Chapel Hill Iron Works, Huddersfield.

1865. Brock, Walter, Messrs. Denny and Co., Engine Works, Dumbarton.

1852. Brogden, Henry, Sale, near Manchester. (*Life Member.*)

1877. Bromley, Massey, Manager, Great Eastern Railway Locomotive Works, Stratford, London, E.

1874. Brotherhood, Peter, Messrs. Brotherhood and Hardingham, 56 Compton Street, Goswell Road, London, E.C.; and 25 Ladbroke Gardens, Notting Hill, London, W.

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1869. Browne, Benjamin Chapman, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1869. Browne, Walter Raleigh, 10 Victoria Chambers, Victoria Street, Westminster, S.W.

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W.

1870. Brunlees, James, 5 Victoria Street, Westminster, S.W.

1872. Brunner, Henry, Messrs. John Hutchinson and Co.'s Alkali Works, Widnes; and Cliff House, Appleton, Widnes.

1866. Bryham, William, Rose Bridge and Douglas Bank Collieries, near Wigan.

1873. Buckley, Robert Burton, Assistant Engineer, Indian Public Works Department, Deegate Lodge, Dinapore, Bengal, India: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.
1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, Lower King Street, Manchester.
1877. Burgess, James Fletcher, Messrs. Ormerod Grierson and Co., 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1874. Burn, William Edward, 171 Portland Road, Newcastle-on-Tyne.
1871. Burrows, James, Douglas Bank, Wigan.
1877. Burton, Clerke, Post Office Chambers, Bute Docks, Cardiff.
1870. Bury, William, 5 New London Street, London, E.C.
1856. Butler, Ambrose Edmund, Kirkstall Forge, near Leeds.
1859. Butler, John, Stanningley Iron Works, near Leeds.
1859. Butler, John Octavius, Kirkstall Forge, near Leeds.

1871. Cabry, Charles, District Resident Engineer, North Eastern Railway, York.
1857. Cabry, Joseph, Resident Engineer, Blyth and Tyne Railway, Newcastle-on-Tyne.
1847. Cammell, Charles, Cyclops Steel and Iron Works, Sheffield.
1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.
1864. Campbell, David, 105 Eglinton Street, Glasgow.
1869. Campbell, James, Hunslet Engine Works, Leeds.
1860. Carbutt, Edward Hamer, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford; and St. Ann's, Burley, Leeds.
1875. Cardozo, Francisco Corrêa de Mesquita, Messrs. Cardozo and Irmâo, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.). (*Life Member.*)
1869. Carpmael, Frederick, 31 Berners Street, Ipswich.
1866. Carpmael, William, 24 Southampton Buildings, London, W.C.
1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.
1868. Carrington, Thomas, Mining Engineer, Kiveton Park Collieries, near Sheffield; and High Hazels, Darnall, near Sheffield.
1874. Carrington, William T. H., 76 Cheapside, London, E.C.
1858. Carson, James Irving, Locomotive Superintendent, West Hartlepool Harbour and Railway, Stockton-on-Tees.
1876. Carson, William, Engineer, Wallasey Local Board, Egremont, Birkenhead.
1877. Carter, Claude, Manager, Messrs. George Carter and Co., Manchester Machine Tool Works, Cornwall Street, Openshaw, Manchester.
1877. Carter, William, Managing Engineer, Smethwick Tube Works, Birmingham.
1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1869. Caspersen, Hans William, Engineer, Danish Government Railway Service, 164 Rye Hill, Newcastle-on-Tyne.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1871. Chamberlain, Walter, 203 Hagley Road, Edgbaston, Birmingham.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 11 Rue Louis-le-Grand, Paris.

1877. Chater, John, Messrs. Henry Pooley and Son's, 89 Fleet Street, London, E.C.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham.

1867. Chatwood, Samuel, Lancashire Safe and Lock Works, Bolton.

1869. Checkley, Thomas, Mining Engineer, Lichfield Street, Walsall.

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1877. Chisholm, John, Messrs. Fairbairn Kennedy and Naylor's Works, Wellington Foundry, Leeds.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1869. Clapham, Robert Calvert, Earsdon, near Newcastle-on-Tyne.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan.

1859. Clark, George, Southwick Engine Works, near Sunderland.

1867. Clark, George, Jun., Southwick Engine Works, near Sunderland.

1867. Clark, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Rodgers, Railway Foundry, Jack Lane, Leeds.

1869. Clarke, William, Messrs. Clarke Watson and Gurney, Victoria Works, South Shore, Gateshead.

1859. Clay, William, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and D 7 Exchange Buildings, Liverpool.

1875. Clayton, Charles, Soho Foundry, Preston.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1871. Cleminson, James, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1873. Clench, Frederick, Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and The Grange, Stourbridge.

1860. Cochrane, Henry, Ormesby Iron Works, Middlesbrough.

1854. Cochrane, John, 6 Westminster Chambers, Victoria Street, Westminster, S.W.

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.
1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.
1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.
1864. Coddington, William, Ordnance Cotton Mill, Blackburn.
1876. Coe, William John, 1 Rumford Place, Liverpool.
1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield; and Tapton Grove, Chesterfield.
1867. Coke, William Langton, District Engineer, Cape Government Railways, Port Elizabeth, Algoa Bay, Cape of Good Hope; (or care of William Sacheverell Coke, Brookhill Hall, near Alfreton.)
1877. Coley, Henry, Manager, Messrs. S. Owens and Co., Whitefriars Street, Fleet Street, London, E.C.
1873. Collingham, Robert Moss, Green Lane Foundry, Queen's Dock Side, Hull.
1874. Conyers, William, Superintending Engineer, New Zealand Railways, Dunedin, Otago, New Zealand.
1877. Cooper, Arthur, Engineer, Messrs. Brown Bailey and Dixon, Sheffield Steel and Iron Works, Sheffield.
1875. Cooper, Frederick, Chief Engineer, H. M. Gun Carriage Department, Bombay.
1877. Cooper, George, Engineer and General Manager, Buenos Ayres Great Southern Railway, Buenos Ayres: (or care of Secretary, Buenos Ayres Great Southern Railway, 4 Great Winchester Street, London, E.C.)
1874. Cooper, William, Messrs. Gilbert and Cooper, Engineers and Iron Shipbuilders, Neptune Iron Works, Hull.
1848. Corry, Edward, 8 New Broad Street, London, E.C.
1875. Cotton, Francis Michael, Messrs. Field Field and Cotton, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.
1875. Cottrill, Robert Nivin, Beehive Works, Bolton.
1868. Coulson, William, Mining Engineer, Shamrock House, Durham.
1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.
1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Foundry, Brook Street, Nottingham.
1870. Cowen, George Roberts, Beck Foundry, Brook Street, Nottingham.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.
1876. Crampton, Willoughby, Messrs. Crampton Brothers, Central Tool Works, Sheffield; and 37 Queen Street, Cannon Street, London, E.C.
1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.

1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.

1877. Crompton, Rookes Evelyn Bell, Messrs. T. H. P. Dennis and Co., Anchor Iron Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C.

1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.

1871. Crossley, William, Furness Iron and Steel Works, Askam, near Dalton-in-Furness, Lancashire.

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester.

1863. Crow, George, Messrs. R. Stephenson and Co.'s Works, Newcastle-on-Tyne.

1874. Curry, William, Locomotive Superintendent, Great Northern Railway of Ireland, Dublin.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester.

1876. Cuss, Henry Berriman, Wiltshire House, Bradford, Manchester.

1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E.

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's.

1866. Daniel, Edward Freer, Messrs. Thornewill and Warham's Iron Works, Burton-on-Trent; and 75 Branstone Road, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds; and 37 Camp Road, Leeds.

1865. Darby, Abraham, Treberfydd, Bwlch, Brecknockshire.

1864. Darby, Charles E., Brymbo Iron Works, near Wrexham.

1873. Davey, Henry, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds.

1865. Davidson, James, Royal Arsenal, Laboratory Department, Woolwich.

1874. Davis, Alfred, Messrs. Hathorn Davis Campbell and Davey, Sun Foundry, Dewsbury Road, Leeds; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.

1868. Davis, Henry Wheeler, 11 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 64 Cannon Street, London, E.C.

1877. Davison, John Walter, Assistant Locomotive Superintendent, Moscow Riazan Railway, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Daw, Samuel, 1 Parade, Tredegarville, Cardiff.

1849. Dawes, George, Milton and Elsecar Iron Works, near Barnsley.
1861. Dawson, Benjamin, Engineer, Haswell Colliery, Fence Houses.
1876. Dawson, Thomas Joseph, Mining Engineer, Cocken, near Fence Houses.
1877. Dawson, William, Metropolitan Railway Carriage and Wagon Co.'s Works, Saltley, Birmingham.
1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.
1874. Deacon, George Frederick, Borough Engineer, Municipal Offices, Dale Street, Liverpool.
1874. Deakin, Thomas, Sandon Street Engine Works, Broughton Road, Salford, Manchester.
1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon.
1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.
1877. Dees, James Gibson, 36 King Street, Whitehaven.
1858. Dempsey, William, 26 Great George Street, Westminster, S.W.
1872. Denton, John Punshon, Tanton Hall, Stokesley, near Northallerton.
1868. Derham, John J., Brookside, near Blackburn.
1875. Dickinson, William, Messrs. Eastons and Anderson, 3 Whitehall Place, London, S.W.
1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton.
1868. Dodman, Alfred, St. James's Iron Works, Lynn.
1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.
1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Blue Anchor Road, Bermondsey, London, S.E.
1877. Dossor, Arthur Loft, Messrs. Dossor Nelson and Weddall, Phœnix Iron Works, Humber Street, Hull.
1865. Douglas, Charles P., Consett Iron Works, near Blackhill, County Durham.
1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Iron and Engine Works, Carlisle; and Viewfield, Stanwix, near Carlisle.
1873. Dove, George, Jun., Redbourn Hill Iron and Coal Co.'s Works, Frodingham, near Brigg.
1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.
1874. Dredge, James, 37 Bedford Street, Strand, London, W.C.
1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.
1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.
1870. Dunlop, James Wilkie, 22 Leadenhall Street, London, E.C.
1857. Dunlop, John Macmillan, Holehird, Windermere.

1864. Dunn, Thomas Edward, Kurhurballee Collieries, Chord Line East Indian Railway, viâ Muddapur Junction, India; and The Cottage, Rusper, near Horsham.

1875. Durie, James, 148 Waterloo Road, Manchester.

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, Messrs. Eastons and Anderson, 3 Whitehall Place, London, S.W.

1867. Easton, James, Mining Engineer, Nest House, Gateshead.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1871. Edwards, Edgar James, Butterley Iron Works, Alfreton.

1877. Edwards, Frederick, Superintending Engineer, Weymouth and Channel Islands Steam Packet Co., &c., 127 Leadenhall Street, London, E.C.

1866. Elce, John, 11 Mansfield Chambers, St. Ann's Square, Manchester.

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1869. Elliott, Henry Worton, Metal Sheathing Works, 10 Coleshill Street, Birmingham; and Selly Oak Works, near Birmingham.

1877. Elliott, Thomas Mark, Messrs. Robert Elliott and Sons, Pensher Foundry, Fence Houses.

1870. Elsdon, Robert, 76 Manor Road, Upper New Cross, London, S.E.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1860. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 1 Avenue Trudaine, Paris.

1875. Elwell, Thomas, Jun., Engineer, Messrs. Varrall Elwell and Middleton's Works, 1 Avenue Trudaine, Paris.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1865. Evers, Frank, Cradley Iron Works, near Stourbridge.

1869. Eyth, Max, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, Wellington Foundry, Leeds; and 15 Portman Square, London, W.

1869. Fairless, John, Forth Banks Engine Works, Newcastle-on-Tyne.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, Messrs. Hayward Tyler and Co.'s Works, 84 Upper Whitecross Street, London, E.C. ; and 31 Wilberforce Road, Finsbury Park, London, N.

1872. Fearn, John Wilmot, Mining Engineer, 31 Devonshire Street, Chesterfield; and Newbold Road, Chesterfield.

1876. Fell, John Corry, 23 Rood Lane, Fenchurch Street, London, E.C.

1877. Fenton, James, Manager, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E.

1870. Ferguson, Henry Tanner, District Locomotive Superintendent, Great Indian Peninsula Railway, Egutpoora, near Bombay, India.

1854. Fernie, John, care of Robert W. Fernie, Swinburne Street, Derby.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, Platt Lane Colliery, Wigan.

1867. Field, Edward, Messrs. Field Field and Cotton, Chandos Chambers, Buckingham Street, Adelphi, London, W. C.

1861. Field, Joshua, 110 Westminster Bridge Road, Lambeth, London, S.E.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1865. Filliter, Edward, Resident Engineer, Leeds Water Works, 16 East Parade, Leeds.

1868. Firth, Arthur, Leeds Iron Works, Leeds.

1868. Firth, Samuel, 26 Alexandra Villas, Finsbury Park, London, N.

1874. Firth, William, Burley Wood, Leeds.

1871. Fisher, Benjamin Samuel, Locomotive Superintendent, Somerset and Dorset Railway, Highbridge, near Bridgwater.

1877. Flannery, James Fortescue, Broadway Chambers, Westminster, S.W.

1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Westbromwich.

1847. Fletcher, Edward, Locomotive Superintendent, North Eastern Railway, Gateshead.

1858. Fletcher, Henry Allason, Messrs. Fletcher Jennings and Co., Lowca Engine Works, Whitehaven. (*Life Member.*)

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1857. Fletcher, James, Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.

1867. Fletcher, Lavington Evans, Chief Engineer, Association for the Prevention of Steam Boiler Explosions, 9 Mount Street, Albert Square, Manchester.

1872. Flower, James J. A., Messrs. James Flower and Sons, Cape Town, Cape of Good Hope; and 9 America Square, Crutched Friars, London, E.C.

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1861. Forster, Edward, Messrs. Chance Brothers and Co.'s Glass Works, Spon Lane, near Birmingham.

1869. Forster, George Baker, Backworth, Newcastle-on-Tyne.

1861. Foster, Sampson Lloyd, 2 Prince's Place, Duke Street, St. James', London, S.W.; and Callipers Hall, Chipperfield, Rickmansworth, Herts.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1866. Fowler, George, Mining Engineer, Basford Hall, near Nottingham.

1847. Fowler, John, 2 Queen Square Place, Westminster, S.W.

1866. Fox, Charles Douglas, 5 Delahay Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1859. Fraser, John, 13 Park Square, Leeds.

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E.

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield.

1852. Froude, William, F.R.S., Chelston Cross, Torquay.

1866. Fry, Albert, Bristol Wagon Works, Temple Gate, Bristol.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., Director of Works and Public Buildings, 12 Whitehall Place, London, S.W.; and 12 Chester Street, Grosvenor Place, London, S.W.

1870. Garstang, James H., General Manager, Signal Construction Works, Monmouth Street, Bridgwater.

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough.

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham.

1870. Gibson, John, Engineer, Ryhope Colliery, near Sunderland.

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1856. Gilkes, Edgar, Messrs. Hopkins Gilkes and Co., Tees Engine Works, Middlesbrough.

1876. Gillett, John, Messrs. Spencer and Gillett, Melksham Foundry, Melksham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1867. Gooch, William Frederick, Vulcan Foundry, Warrington.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, Goldsmith Buildings, Temple, London, E.C.

1875. Goodfellow, George Ben, Hyde Iron Works, Hyde, near Manchester.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden.

1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1877. Goulty, Wallis Rivers, Albert Chambers, Albert Square, Manchester.

1871. Gowenlock, Alfred Hargreaves, Messrs. Jessop and Co., Railway Contractors, 93 Clive Street, Calcutta; and Pagoda Lodge, Thurlow Place, Lower Norwood, London, S.E.

1869. Grainger, James Nixon, Public Works Department, Chepank, Madras: (or care of G. N. Henton, 88 Alexandra Terrace, Newport, Isle of Wight.)

1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 127 Queen's Road, Peckham, London, S.E.

1876. Gray, John William, Engineer, Corporation Water Works, Broad Street, Birmingham.

1870. Gray, Matthew, 106 Cannon Street, London, E.C.; and Silvertown Telegraph Works, North Woolwich, E.

1870. Greaves, James Henry, 2 Great George Street, Westminster, S.W.

1861. Green, Edward, Jun., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.

1874. Greenwood, William Henry, Dom Dossona, Farforavai, St. Petersburg: (or care of J. E. Greenwood, 53 Warwick Street, Hulme, Manchester.)

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1874. Grew, Nathaniel, 8 New Broad Street, London, E.C.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1860. Grice, Frederic Groom, Ansty's Lea, Torquay.

1868. Grierson, Henry Houldsworth, Messrs. Ormerod Grierson and Co., St. George's Iron Works, Hulme, Manchester.

1873. Griffiths, John Alfred, Department of Public Works, Railway Branch, Chief Engineer's Office, Brisbane, Queensland: (or care of Thomas Griffiths, Higher Crumpsall, Cheetham Hill, Manchester.)

1874. Griffiths, John R., Manager, Ebbw Vale Co.'s Iron Works, Pontypool.

1876. Grundy, Ralph Darling, Wigan Coal and Iron Co.'s Works, Kirkless Hall, Wigan.

1877. Grundy, Robert, Manager, Hindley Field Collieries, Bickershaw, Wigan.

1870. Guilford, Francis Leaver, Messrs. Cowen and Co., Beck Foundry, Brook Street, Nottingham.

1870. Gwynne, James Eglinton Anderson, Essex Street Works, Strand, London, W.C. (*Life Member.*)

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1863. Hackney, William, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1871. Hall, William Silver, Messrs. Hall West and Co., Abbey Works, Nuneaton.

1871. Halpin, Druitt, Victoria Graving Docks, London, E.

1870. Hamand, Arthur Samuel, Stephenson Chambers, New Street, Birmingham.

1860. Hamilton, Gilbert, Messrs. James Watt and Co., Soho Foundry, near Birmingham; and Leicester House, Kenilworth Road, Leamington.

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Campinas, Sâo Paulo, Brazil.

1870. Hannah, Joseph Edward, Abbeystead, Wyresdale, near Lancaster.

1874. Harding, William Bishop, care of Messrs. Robey and Co., 1 Euler Strasse, Budapest, Hungary.

1869. Hartield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1873. Harman, Harry Jones, Cornwall Buildings, 35 Queen Victoria Street, London, E.C.

1873. Harris, Richard Henry, Upper Tooting, London, S.W.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1871. Harrison, Joseph Edward, Woodside Iron Works, near Dudley.

1858. Harrison, Thomas Elliot, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1865. Harrrison, William Arthur, Messrs. Allen Harrison and Co., Cambridge Street Works, Manchester.

1874. Hart, James, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.

1877. Hart, James, Borough Engineer and Surveyor, Town Hall, St. Helen's.

1872. Hartnell, Wilson, Rodborough, Stroud, Gloucestershire.

1871. Hartness, John, Lloyd's Inspector, Wear Chain and Anchor Testing Works, Sunderland.

1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.

1857. Haughton, S. Wilfred, Greenbank, Carlow, Ireland. (*Life Member.*)

1861. Hawkins, William Bailey, 2 Suffolk Lane, Cannon Street, London, E.C.

1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.

1856. Hawksley, Thomas, 30 Great George Street, Westminster, S.W.

1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.
1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar.
1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough.
1860. Head, John, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1873. Headly, Lawrance, 8 Newnham Terrace, Cambridge.
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1872. Heap, William, 9 Rumford Place, Liverpool.
1864. Heathfield, Richard, Lion Galvanising Works, Wiggin Street, Icknield Port Road, Birmingham.
1875. Heenan, Richard Hammersley, Executive Engineer, Public Works Department, Bhawulpoor, viâ Mooltan, Punjaub, India: (or care of Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.)
1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.
1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool.
1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.
1877. Hepworth, Thomas Howard, Manager, Messrs. A. Robinson and Co., Mersey Wheel Works, Derby.
1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester.
1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester.
1865. Hewett, Edward Edwards, High Court, High Street, Sheffield.
1872. Hewlett, Alfred, Wigan Coal and Iron Works, Kirkless Hall, Wigan.
1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.
1871. Hick, John, M.P., Mytton Hall, Whalley, near Blackburn.
1864. Hide, Thomas C., Messrs. Hide and Thompson, 4 Cullum Street, Fenchurch Street, London, E.C.
1870. Higson, John, Mining Engineer, St. George's Chambers, Albert Square, Manchester.
1873. Hildebrandt, John Albert Reinhold, Bow Chambers, 55 Cross Street, Manchester.
1871. Hill, Alfred C., Royal Exchange, Middlesbrough; and Newcomen Street, Coatham, Redcar.
1867. Hill, Henry Walker, 51 Hampden Street, Nottingham.
1873. Hilton, Franklin, Ebbw Vale Steel, Iron, and Coal Co., Ebbw Vale, Monmouthshire.
1869. Hind, Henry, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham.
1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham.

1874. Hird, Holmes, Engineer, Messrs. Bass and Co.'s Brewery, Burton-on-Trent.
1870. Hodges, Petronius, Yorkshire Steel and Iron Works, Penistone, near Sheffield.
1858. Hodgson, Robert, North Eastern Railway, Newcastle-on-Tyne.
1852. Holcroft, James, Norton, near Stourbridge.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1871. Holiday, Joseph, Union Foundry, Cutler Heights, near Bradford.
1865. Holliday, John, Messrs. John Bethell and Co., Creosote Works, Westbromwich; and Oakfield Lodge, Booth Street, Handsworth, Birmingham.
1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.
1873. Holt, Henry Percy, Royal Insurance Buildings, Leeds.
1867. Holt, William Lyster, St. Stephen's Club, Westminster, S.W.
1867. Homer, Charles James, Mining Engineer, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent; and Caverswall Castle, Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.
1856. Hopkinson, John, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.
1874. Hopkinson, John, Jun., D.Sc., Manager, Lighthouse and Optical Department, Messrs. Chance Brothers and Co.'s Glass Works, Spon Lane, near Birmingham; and 4 Westminster Chambers, Victoria Street, Westminster, S.W.
1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.
1867. Hopper, William, Machine Works, Moscow: (or care of Thomas Hopper, 46 Queen Street, Edinburgh.)
1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.
1868. Horsley, Thomas, King's Newton, near Derby.
1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.
1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.
1875. Hosgood, Thomas Hopkin, Troedyrhiew, Merthyr Tydvil.
1873. Hoskin, Richard, 1 East Parade, Sheffield.
1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, Messrs. J. and F. Howard, Britannia Iron Works, Bedford.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howe, William, Clay Cross Coal and Iron Works, near Chesterfield.

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield.

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W.

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

873. Hughes, Henry, Falcon Iron Works, Loughborough.

1871. Hughes, Joseph, Messrs. Fletcher Jennings and Co.'s, Lowca Engine Works, Whitehaven.

1864. Hulse, William Wilson, Whalley Chambers, 88 King Street, Manchester.

1866. Humphrys, Robert Harry, Deptford Pier, London, S.E.

1859. Hunt, James P., Corngreaves Iron Works, near Birmingham.

1856. Hunt, Thomas, care of H. R. Hunt, Superintendent of Locomotive and Permanent Way Department, Isle-of-Man Railway, Douglas, Isle-of-Man.

1874. Hunt, William, Jun., Messrs. William Hunt and Sons, Alkali Works, Lea Brook, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E.

1864. Hutchinson, Edward, Stotely, Haslemere, Surrey.

1865. Hyde, Colonel Henry, R.E., India Office, Westminster, S.W. (*Life Member.*)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1867. Inglis, William, Soho Iron Works, Bolton; and Astley Bridge, near Bolton.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and D 7 Exchange Buildings, Liverpool.

1872. Jack, Alexander, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1876. Jackson, Henry James, Superintending Engineer, General Steam Navigation Co.'s Works, Deptford, London, S.E.

1870. Jackson, John P., Mining Engineer, Clay Cross Coal and Iron Works, near Chesterfield.

1859. Jackson, Matthew Murray, Engineer-in-Chief, Imperial Danube Steam Navigation Works, Pesth, Austria.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Grosmont, near Hereford.

1860. Jackson, Samuel, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1873. Jackson, Samuel, Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, Windsor Iron Works, Garston, near Liverpool.

1876. Jacobs, Charles Mattathias, Post Office Chambers, Bute Docks, Cardiff.

1866. Jaeger, Herrmann Frederic, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1856. James, Jabez, 40 Prince's Street, Commercial Road, Lambeth, London, S.E.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1870. Jamieson, John Lennox Kincaid, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.

1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation, Birmingham; and The Laurels, Shrewsbury.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1863. Jeffreys, Edward A., Low Moor Iron Works, near Bradford.

1876. Jemson, James, Engineer to the Kay Shuttleworth Mineral Estate, Gawthorpe Hall, near Burnley.

1875. Jenkin, H. C. Fleeming, F.R.S., Professor of Engineering, University of Edinburgh; 3 Great Stuart Street, Edinburgh.

1854. Jobson, John, Derwent Foundry, Derby.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne.

1872. Jones, Charles, Messrs. John Jones and Sons, Marine Engine Works, William Street, Liverpool.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Laburnum House, Sutton Street, Aston, Birmingham.

1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.

1867. Jones, George Edward, care of Messrs. James Nicol Fleming and Co., Calcutta: (or care of Edward Jones, Wylde Green, near Birmingham).

1869. Jones, John, Iron Trade Offices, Royal Exchange, Middlesbrough.

1877. Jones, William, Stamford Works, Guide Bridge, near Manchester.

1872. Jones, William Richard Sumption, Executive Engineer, Workshops Division, Lower Ganges Canal, Narora, viâ Aligarh, India: (or care of J. H. S. Jones, Garth Villa, Bassaleg, near Newport, Monmouthshire).

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1867. Kellett, John, 27 King Street, Wigan.

1873. Kelson, Frederick Colthurst, 3 Onslow Road, Elm Park, Fairfield, Liverpool.

1863. Kennan, James, Agricultural Implement Works, 19 Fishamble Street, Dublin.

1847. Kennedy, James, Cressington Park, Aigburth, Liverpool.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Wellington Foundry, Leeds.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Maple Bank, Church Road, Edgbaston, Birmingham.

1866. Kershaw, John, 9 Great Queen Street, Westminster, S.W.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1870. Kinsey, Henry, Postern Buildings, Swansea.

1872. Kirk, Alexander Carnegie, Messrs. John Elder and Co., Engineers and Shipbuilders, 12 Centre Street, Glasgow; and Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington.

1875. Kirkwood, James, Chief Engineer, Revenue Steamer "Fei-Hu," Hong Kong, China: (or care of F. Degenaer, Zetland Street, Hong Kong, China.)

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W.

1859. Kitson, Frederick William, Monkbridge Iron Works, Leeds.

1848. Kitson, James, Airedale Foundry, Leeds.

1859. Kitson, James, Jun., Monkbridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds.

1874. Klein, Thorvald, Works Manager, Messrs. Brown Marshalls and Co., Britannia Railway Carriage and Wagon Works, Birmingham.

1875. Knight, John Henry, Weybourne House, Farnham.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.
1873. Lamb, William James, Newtown and Meadows Collieries, near Wigan.
1863. Lancaster, John, Bilton Grange, Rugby.
1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.
1867. Lawrence, Henry, The Grange Iron Works, Durham.
1874. Laws, William George, Central Buildings, 18 Grainger Street West, Newcastle-on-Tyne.
1870. Layborn, Daniel, Government Engineer Surveyor, Rangoon, Burmah, India: (or care of Ellery Turner, Norwood, Beverley.)
1856. Laybourne, Richard, Rhymney Iron Works, Rhymney, Monmouthshire.
1860. Lea, Henry, 35 Paradise Street, Birmingham.
1865. Ledger, Joseph, Keswick.
1862. Lee, J. C. Frank, 22 Great George Street, Westminster, S.W.
1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.
1874. Lees, James, Long Island Iron Works, Carlisle.
1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.
1866. Leigh, Joseph D., Ellesmere Foundry, Patricroft, near Manchester.
1858. Leslie, Andrew, Iron Shipbuilding Yard, Hebburn Quay, Gateshead.
1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons', Tyne Hæmatite Iron Works, Scotswood-on-Tyne.
1872. Lewis, Rowland Watkin, Britannia Boiler Tube Works, Ettingshall, Wolverhampton.
1860. Lewis, Thomas William, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.
1856. Linn, Alexander Grainger, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1872. Linsley, Samuel W., 13 Victoria Terrace, South Shields.
1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.
1866. Little, George, Messrs. Platt Brothers and Co.'s, Hartford Iron Works, Oldham.
1867. Livesey, James, 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1873. Llewellyn, William Hely, Messrs. Llewellyn and Cubitt, Rhondda Engine Works, Pentre, Rhondda Valley, Pontypridd.
1867. Lloyd, Charles, Glebe Buildings, Stoke-upon-Trent.
1863. Lloyd, Edward R., Albion Tube Works, Nile Street, Birmingham.
1871. Lloyd, Francis Henry, Darlaston Steel and Iron Works, near Wednesbury; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite, Messrs. Lloyds, High Street, Birmingham. (*Life Member.*)

1862. Lloyd, John, Lilleshall Iron Works, Oakengates, near Wellington, Shropshire.

1864. Lloyd, Sampson Zachary, Darlaston Steel and Iron Works, Wednesbury; and Areley Hall, Stourport.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1862. Lloyd, Wilson, Myvod House, Wood Green, Wednesbury.

1863. Loam, Matthew Hill, Gas and Water Engineer, Ivy House, Colwich Road, Nottingham.

1869. Lockhart, Humphrey Campbell, Messrs. Pilkington Brothers' Plate Glass Works, St. Helen's.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1856. Longridge, Robert Bewick, Chief Engineer, Steam Boiler Insurance Company, 67 King Street, Manchester.

1875. Longridge, Robert Charles, Assistant Manager, Steam Boiler Insurance Company, 67 King Street, Manchester.

1865. Longridge, William Smith, Oakfield, West End, Esher.

1861. Low, George, Bishop's Hill Cottage, Ipswich.

1873. Lowe, John Edgar, 2 Laurence Pountney Hill, London, E.C.

1873. Lucas, Arthur, 23 Delahay Street, Westminster, S.W.

1872. Lukin, Augustus Stephen, Newbold Road, Chesterfield: (or care of Rev. E. Banks, Coleshill Vicarage, Highworth, near Swindon.)

1877. Lupton, Arnold, Mining Engineer, Bettisfield Colliery, Bagillt, near Holywell.

1854. Lynde, James Gascoigne, City Hall, Manchester.

1868. Lyndon, George Frederick, Minerva Works, Fazeley Street, Birmingham.

1877. MacColl, Hector, 65 West Regent Street, Glasgow.

1864. Macfarlane, Walter, Saracen Foundry, Washington Street, Glasgow.

1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka; and Oriental Bank Corporation, Kobe, Japan: (or care of Dr. Maclagan, 136 Nethergate, Dundee.)

1877. MacLellan, John A., Messrs. Alley and MacLellan, 33 Virginia Street, Glasgow.

1864. Macnab, Archibald Francis, Japanese Government Service, Yokohama, Japan.

1865. MacNay, William, Shildon Engine Works, Darlington.

1865. Macnee, Daniel, Brinsworth Iron and Steel Works, Rotherham.

1873. Mair, John George, Manager, Messrs. Simpson and Co.'s Engine Works, Grosvenor Road, Pimlico, London, S.W.

1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.

1862. Mansell, Richard Christopher, Mechanical Engineer, South Eastern Railway, Ashford.

1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1862. Mappin, Frederick Thorpe, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred, Perseverance Iron Works, Heneage Street, Whitechapel, London, E.; and Laurel Bank, Prospect Hill, Walthamstow, Essex. (*Life Member.*)

1865. Marshall, Francis Carr, Messrs. Hawthorn and Co., Newcastle-on-Tyne.

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.

1877. Marshall, William Bayley, 6 Portland Road, Edgbaston, Birmingham.

1859. Marshall, William Ebenezer, 20 Esplanade, Scarborough.

1847. Marshall, William Prime, 6 Portland Road, Edgbaston, Birmingham.

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge.

1853. Marten, Henry John, Parkfield House, near Wolverhampton.

1867. Martin, William, 13 Avenue de la Reine Hortense, Paris.

1857. Martindale, Lt.-Colonel Ben Hay, C.B., R.E., General Manager, London and St. Katharine Docks, Dock House, 109 Leadenhall Street, London, E.C.

1854. Martineau, Francis Edgar, Globe Works, 278 New Town Row, Birmingham.

1876. Mather, John, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester.

1875. Matthews, James, 2 Lion Chambers, Broad Street, Bristol.

1875. Matthews, Thomas William, Messrs. Leather Matthews and Co., Broughton Road Iron Works, Salford, Manchester.

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1853. Maudslay, Henry, care of John Barnard, 8 Lancaster Place, Strand, London, W.C. (*Life Member.*)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 37 Bedford Street, Strand, London, W.C.
1861. May, Robert Charles, 6 Great George Street, Westminster, S.W.
1857. May, Walter, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.
1865. Maylor, John, Churton Lodge, Churton, near Chester.
1859. Maylor, William, care of Messrs. Stanes Watson and Co., 4 Cullum Street, Fenchurch Street, London, E.C.
1874. McClean, Frank, 23 Great George Street, Westminster, S.W.
1872. McConnochie, John, Engineer to the Bute Harbour Trust, New Works, Bute Docks, Cardiff.
1865. McDonnell, Alexander, Locomotive Superintendent, Great Southern and Western Railway, Dublin.
1868. McKay, Benjamin, 3 Rouville Terrace, St. Helier's, Jersey.
1872. McNeile, Alexander, Messrs. McNeile Brothers, Wheel and Axle Works, 26 John Street, Pentonville Road, London, N.
1863. Meek, Sturges, Resident Engineer, Lancashire and Yorkshire Railway, Manchester.
1858. Meik, Thomas, 6 York Place, Edinburgh.
1857. Menelaus, William, Dowlais Iron Works, Dowlais.
1876. Menzies, William, Messrs. Menzies and Blagburn, King Street, Newcastle-on-Tyne.
1877. Merryweather, Henry, Messrs. Merryweather and Sons, Steam Fire-Engine Works, York Street, York Road, Lambeth, London, S.E.
1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, 63 Long Acre, London, W.C.
1867. Merryweather, Richard M., Messrs. Merryweather and Sons, Fire-Engine Works, 63 Long Acre, London, W.C.
1877. Michele, Vitale Domenico de, 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1862. Miers, Francis C., Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.; and Stoneleigh Lodge, Grove Road, Clapham Park, London, S.W.
1864. Miers, John William, 74 Addison Road, Kensington, London, W.
1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.
1856. Mitchell, Charles, Iron Shipbuilding Yard, Low Walker, Newcastle-on-Tyne.
1870. Moberly, Charles Henry, Messrs. Eastons and Anderson's, Erith Iron Works, Erith, London, S.E.
1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.
1859. Moor, William, Engineer, Hetton Colliery, Hetton, near Fence Houses.
1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)

1872. Moorsom, Warren Maude, London and North Western Railway, Locomotive Department, Crewe.

1867. Morgans, Thomas, The Guildhall, Bristol.

1874. Morris, Edmund Legh, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

1868. Morris, William, Waldridge Colliery, Chester-le-Street.

1865. Mosse, James Robert, Public Works Office, Colombo, Ceylon.

1858. Mountain, Charles George, Messrs. May and Mountain, Suffolk Works, Berkley Street, Birmingham.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, Engineer, Rochdale Canal Navigation, Rochdale.

1863. Muir, William, 16 Clyde Terrace, Brockley Road, New Cross, London, S.E.

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1872. Mulliner, Charles, 29 Blackfriars, Manchester.

1865. Murdock, William Mallabey, Barrow Hæmatite Steel Works, Barrow-in-Furness.

1859. Murphy, James, Railway Works, Newport, Monmouthshire.

1858. Murray, Thomas H., Engine Works, Chester-le-Street.

1863. Musgrave, John, Globe Iron Works, Bolton.

1876. Naish, William Prideaux, Messrs. Naish and Osborn's, Birmingham Iron Foundry, 20 Coleshill Street, Birmingham.

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1848. Napier, John, Saughfield House, Hillhead, Glasgow.

1861. Naylor, John William, Wellington Foundry, Leeds.

1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1869. Nelson, James, Marine and Stationary Engine Works, Gateshead.

1860. Nettlefold, Joseph Henry, Screw Works, Broad Street, Birmingham.

1866. Newdigate, Albert Lewis, 2 The Pavement, Clapham Common, London, S.W. (*Life Member.*)

1862. Newton, William Edward, 66 Chancery Lane, London, W.C.

1876. Newton, William Manfield, Messrs. John Brierly and Sons', Railway Signal Engineers, 32 Piccadilly Circus, London, W.

1877. Nicolson, Donald, Consulting Engineer, Bombay.

1866. Norfolk, Richard, Beverley Iron and Wagon Works, Beverley.

1850. Norris, Richard Stuart, Wilton Cottage, Kenyon, near Manchester.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1869. North, Frederic William, Mining Engineer, Rowley Hall Colliery, Rowley Regis, near Dudley.

1868. O'Connor, Charles, Messrs. John Elder and Co.'s, Fairfield Engine Works, Govan, Glasgow.

1875. Okes, John Charles Raymond, Manager, Messrs. Hayward Tyler and Co.'s Steam Pump Works, 84 Upper Whitecross Street, London, E.C.

1866. Oliver, William, Victoria and Broad Oaks Iron Works, Chesterfield.

1867. Ohrick, Lewis, 27 Leadenhall Street, London, E.C.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield.

1867. Oughterson, George Blake, Messrs. Manlove Alliott and Co., 45 Rue d'Elbeuf, Rouen, France.

1847. Owen, William, Wheathill Foundry, Rotherham; and Clifton House, Rotherham.

1868. Paget, Arthur, Machine Works, Loughborough.

1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees.

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1871. Parke, Frederick, Withnell Fire-Clay Works and Cotton Mill, near Chorley.

1872. Parker, Thomas, Carriage Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1871. Parkes, Pershouse, Tipton Chain Works, Castle Street, Tipton.

1877. Paton, John McClure Caldwell, Sourabaya, Java: (or care of Messrs. Manlove Alliott and Co., Bloomsgrove Works, Ilkeston Road, Nottingham.)

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co.'s Works, Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester; and Gorton Hall, Gorton, near Manchester.

1874. Peaker, George, Engineer to the Small Arms Ammunition Factory, Kirkee, India.

1873. Pearce, Richard, Deputy Carriage Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 69 Holland Road, Kensington, London, W.

1848. Pearson, John, 15 Old Hall Street, Liverpool; and Golborne Park, near Newton-le-Willows, Lancashire.

1869. Pearson, William Hall, 50 Ann Street, Birmingham.

1866. Peele, Arthur John, Oakley House, Bellevue, Shrewsbury.

1848. Penn, John, F.R.S., The Cedars, Lee, London, S.E. (*Life Member.*)

1873. Penn, John, Jun., Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. Percy, Cornelius McLeod, Wigan Coal and Iron Co.'s Works, Kirkless Hall, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1863. Perry, Thomas J., Highfields Engine Works, Bilston.

1865. Perry, William, Messrs. Samuel Perry and Sons, Wednesbury.

1867. Pidgeon, Daniel, Holmwood, Putney Hill, London, S.W.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham.

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France.

1875. Platt, Edward, Messrs. Ackroyd and Platt, Albert Iron Works, Sowerby Bridge.

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1869. Player, John, Clydach Foundry, near Swansea.

1866. Plum, Thomas Edward Day, Mansion House Buildings, Queen Victoria Street, London, E.C.

1861. Plum, Thomas William, Old Park Iron Works, near Shifnal.

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1876. Pooley, Henry, Jun., Messrs. Henry Pooley and Son, Albion Foundry, Liverpool.

1860. Ponsonby, Edward Vincent, 1 Torquay Villa, Maindee, Newport, Monmouthshire.

1869. Potter, William Aubone, Mining Engineer, Cramlington House, Cramlington, Northumberland.

1864. Potts, Benjamin Langford Foster, 174 Camberwell Grove, London, S.E.

1851. Potts, John Thorpe, Messrs. Richmond and Potts, 119 South Fourth Street, Philadelphia, Pennsylvania, United States.

1870. Powell, Thomas, (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas, (Nephew), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1867. Powell, William, Harbour Works, Douglas, Isle of Man.
1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.
1856. Preston, Francis, Turnbridge Iron Works and Forge, Huddersfield; and Netherfield House, Kirkburton, near Huddersfield.
1877. Price, Henry Sherley, Albert Chambers, Albert Square, Manchester.
1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and Rose Villa, Gateshead Road, Jarrow.
1875. Prior, Johannes Andreas, Sub-Director, Messrs. Burmeister and Wain's Engineering and Shipbuilding Works, Copenhagen.
1874. Prosser, William Henry, Messrs. Harfield and Co.'s, Mansion House Buildings, Queen Victoria Street, London, E.C.
1875. Provis, George Stanton, District Locomotive Superintendent, East Indian Railway, Assensole, India: (or care of T. J. Provis, The Grange, Ellesmere, near Shrewsbury.)
1866. Putnam, William, Darlington Forge, Darlington.

1873. Radcliffe, Arthur Henry Wright, 7 Union Street, Birmingham.
1870. Radcliffe, William, Moorgate, Rotherham.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1875. Rainford, Arthur, Assistant Superintendent, Messrs. Jessop and Co., Phœnix Foundry, Calcutta.
1847. Ramsbottom, John, Harewood Lodge, Mottram, near Manchester.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W.
1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Head, Orwell Works, Ipswich.
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W.
1867. Ratliffe, George, Mersey Steel and Iron Co.'s Works, Caryl Street, Liverpool.
1862. Ravenhill, John R., Glass House Fields, Ratcliff, London, E.
1872. Rawlins, John, Manager, Metropolitan Railway Carriage and Wagon Co., Saltley Works, Birmingham.
1870. Reed, Edward James, C.B., M.P., Broadway Chambers, Westminster, S.W.
1859. Rennie, George Banks, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1876. Restler, James William, Assistant Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1875. Rich, William Edmund, Engineer, Messrs. Eastons and Anderson, 3 Whitehall Place, London, S.W.

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co.'s Iron Works, Middlesbrough.

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1863. Richardson, The Hon. Edward, Minister of Public Works, Christchurch, Canterbury, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Engineer to Messrs. Robey and Co., Perseverance Iron Works, Lincoln.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff.

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland.

1863. Rigby, Samuel, Messrs. Armitage and Rigbys, Cock Hedge Mill, Warrington.

1871. Rigg, John, Deputy Locomotive Superintendent, London and North Western Railway, Crewe.

1874. Riley, James, Manager, Landore Siemens-Steel Works, Landore, Swansea.

1873. Robertson, George, 4 Three Crown Square, Southwark Street, London, S.E.

1848. Robertson, Henry, M.P., Great Western Railway, Shrewsbury; and 13 Lancaster Gate, London, W.; and Palé, Corwen.

1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Rochdale.

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.

1865. Robinson, John, Messrs. Thomas Robinson and Son, Rochdale.

1866. Robson, Thomas, Mining Engineer, Lumley Colliery, Fence Houses.

1872. Rofe, Henry, Resident Engineer, Nottingham Water Works, St. Peter's Gate, Nottingham; and 111 Forest Road West, Nottingham.

1868. Rogers, William, East London and Queenstown Railway, Queenstown, Cape of Good Hope: (or care of J. Kenyon Rogers, 9A Tower Chambers, Liverpool.)

1871. Rollo, David, Messrs. James Jack, Rollo, and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1867. Rose, Henry Fullwood, Albert Iron Works, Moxley, near Wednesbury.

1867. Rose, Thomas, Machine Works, 37 Victoria Street, Manchester.

1874. Ross, John Alexander George, 34 Collingwood Street, Newcastle-on-Tyne.
1876. Ross, Thomas Braban, Sheepbridge Coal and Iron Works, Chesterfield.
1866. Rosthorn, Joseph De, Messrs. Rosthorn Brothers, Vienna.
1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.
1857. Routledge, William, 4 Parsonage Buildings, Blackfriars, Manchester.
1860. Rumble, Thomas William, Chief Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E. (*Life Member.*)
1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln.
1877. Rutter, Edward, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.
1866. Ryland, Frederick, Messrs. Kenrick's Works, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C.
1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester.
1868. Sacré, Edward Antoine, 26 Parliament Street, Westminster, S.W.
1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 22 Great George Street, Westminster, S.W.)
1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford.
1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N.
1864. Samuda, Joseph D'Aguilar, M.P., Iron Ship Building Yard, Isle of Dogs, Poplar, London, E.
1865. Samuelson, Bernhard, M.P., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.
1871. Sanders, Richard David, Manager, Messrs. James Watt and Co., Soho Foundry, near Birmingham.
1861. Sanderson, George Grant, Redbourn Hill Iron and Coal Works, Frodingham, near Brigg.
1864. Sanderson, John, Weardale and Shildon District Water Works, Tunstall Reservoir, Wolsingham, near Darlington.
1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W.
1875. Saxon, George, Spring Works, Openshaw, Manchester.
1869. Scarlett, James, 14 St. Ann's Square, Manchester.
1876. Scott, David, Cuttack, Orissa, India.
1875. Scott, Frederick Whitaker, Messrs. Scott Brothers' Wire and Hemp Rope Works, West Gorton, Manchester.
1868. Scott, George Lamb, 46 Lancaster Avenue, Fennel Street, Manchester.
1877. Scott, Irving M., Messrs. Prescott Scott and Co., Union Iron Works, San Francisco, California.

1861. Scott, Walter Henry, Locomotive and Carriage Superintendent, Mauritius Railways, Port Louis, Mauritius: (or care of James H. Murray, 14 Marquis Road, Finsbury Park, London, N.)

1868. Scriven, Charles, Messrs. Scriven and Holdsworth, Leeds Old Foundry, Marsh Lane, Leeds.

1864. Seddon, John, 98 Wallgate, Wigan.

1873. Seddon, John Frederick, Mining Engineer, Great Harwood Collieries, near Accrington.

1857. Selby, George Thomas, Smethwick Tube Works, Birmingham.

1867. Selby, Millin, Patricroft Spinning Co., Springfield Mill, Patricroft, near Manchester; and 26 Ducie Street, Oxford Road, Manchester.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Engineers and Contractors, 7 Hastings Street, Calcutta.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Co.'s Works, Birmingham.

1867. Sharpe, Charles James, 27 Great George Street, Westminster, S.W.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 110 Cannon Street, London, E.C.

1864. Shaw, Duncan, Mining Engineer, Cordoba, Spain.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1876. Shield, Henry, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1872. Shirley, Henry Lionel, Engineer, Constantinovskoi Railway, South Russia; and 9 Queen's Gate Terrace, London, S.W.

1872. Shoolbred, James Nelson, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1859. Shuttleworth, Joseph, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln.

1851. Siemens, Charles William, D.C.L., F.R.S., 12 Queen Anne's Gate, Westminster, S.W.; and 3 Palace Houses, Bayswater Road, London, W.

1871. Simon, Henry, 7 St. Peter's Square, Manchester.

1877. Simonds, William Turner, Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 35 Commercial Road, Pimlico, London, S.W.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C.

1857. Sinclair, Robert Cooper, Hartshill, near Atherstone.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1859. Slater, Isaac, Gloucester Wagon Works, Gloucester.
1853. Slaughter, Edward, 4 Clifton Park, Clifton, Bristol.
1876. Smethurst, William, Messrs. Dewhurst Hoyle and Smethurst, Garswood Hall Colliery, Ashton, near Wigan.
1873. Smith, Charles, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.
1866. Smith, Edward Fisher, The Priory Offices, Dudley.
1866. Smith, George Fereday, Grovehurst, Tunbridge Wells.
1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill.
1860. Smith, John, Brass Foundry, Traffic Street, Derby.
1876. Smith, John, Messrs. Thomas Robinson and Son, Rochdale.
1877. Smith, John Paterson, Messrs. P. and W. Maclellan, Clutha Iron Works, Glasgow; and Haughhead Cottage, Glasgow.
1857. Smith, Josiah Timmis, Ulverstone Hæmatite Iron Works, Barrow-in-Furness.
1870. Smith, Michael Holroyd, Caledonia Wire Mills, Halifax.
1857. Smith, William, 18 Salisbury Street, Strand, London, W.C.
1866. Smith, William, Messrs. A. and W. Smith and Co., Eglinton Engine Works, Glasgow.
1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.
1859. Sokoloff, General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., 2 Greengate, Salford, Manchester.)
1858. Sörensen, Bergerius, Engineer-in-Chief, Royal Norwegian Navy Department, Horten Dockyard, Norway: (or care of Henry Tottie, 5 Great Winchester Street Buildings, London, E.C.)
1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.
1865. Sparrow, Arthur, Lane End Iron Works, Longton, near Stoke-upon-Trent.
1865. Sparrow, William Mander, Osier Bed Iron Works, Wolverhampton.
1876. Speck, Thomas Samuel, Resident Engineer and Locomotive Superintendent, Metropolitan District Railway, Lillie Bridge Works, West Brompton, London, S.W.
1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.
1877. Spencer, John, Vulcan Tube Works, Westbromwich.
1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne.
1853. Spencer, Thomas, Blackladies, Penkridge, near Stafford.
1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne.
1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1864. Spittle, Thomas, Cambrian Iron Foundry, Newport, Monmouthshire.
1876. Spriggs, Christopher, 110 Everton Road, Manchester.
1862. Stableford, William, Railway Carriage Works, Oldbury, near Birmingham.
1869. Stabler, James, Messrs. Shand Mason and Co., Fire-Engine Works, 75 Upper Ground Street, Blackfriars Road, London, S.E.
1877. Stanger, George Hurst, Messrs. Goodison and Co., 35A Castle Street, Liverpool.
1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.
1874. Steel, Thomas Dyne, Bank Chambers, Newport, Monmouthshire.
1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.
1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.
1868. Stephenson, George Robert, 24 Great George Street, Westminster, S.W.
1876. Sterne, Louis, Messrs. Thomson Sterne and Co., Crown Iron Works, Glasgow; and 9 Victoria Chambers, Victoria Street, Westminster, S.W.
1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.
1866. Stevenson, John, Acklam Iron Works, Middlesbrough.
1877. Stewart, Alexander, Manager, Messrs. Thwaites and Carbutt, Vulcan Iron Works, Thornton Road, Bradford.
1859. Stewart, Charles P., Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and 92 Lancaster Gate, Hyde Park Gardens, London, W.
1851. Stewart, John, Blackwall Iron Works, Russell Street, Blackwall, London, E.
1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.
1875. Stoker, Frederick William, Manager, Messrs. Shaw Johnson and Reay, The Moor Iron Works, Stockton-on-Tees.
1877. Stokes, Alfred Allen, Chief Assistant Locomotive Superintendent, East Indian Railway, Jumalpore, Bengal: (or care of William Goulding, Summer Hill House, Cork.)
1864. Stokes, James Folliott, Longview, Simla, India.
1863. Storey, John Henry, Knott Mill Brass and Copper Works, Little Peter Street, Manchester.
1877. Stothert, George Kelson, Steam Ship Works, Bristol.
1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton.
1873. Strype, William George, The Murragh, Wicklow.
1861. Sumner, William, 2 Brazennose Street, Manchester.
1875. Sutcliffe, Frederic John Ramsbottom, Manager of Engineering Department, Bowling Iron Works, near Bradford.

1860. Swindell, James Evers, Parkhead Iron Works, Dudley; and Oldswinford, near Stourbridge.

1864. Swindell, James Swindell Evers, Clent House, Stourbridge.

1872. Symington, William Weldon, Bowden Steam Mills, Market Harborough.

1875. Tangye, George, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham.

1861. Tangye, James, Messrs. Tangye Brothers, Cornwall Works, Soho, Birmingham; and Aviary Cottage, Illogan, near Redruth.

1859. Tannett, Thomas, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead.

1862. Taylor, John, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 99 Constitution Hill, Birmingham.

1874. Taylor, Percyvale, Panther Lead Smelting Works, Avon Street, St. Philip's, Bristol.

1862. Taylor, Richard, Mining Engineer, 6 Queen Street Place, Upper Thames Street, London, E.C.

1877. Taylor, William Crees, Board of Trade Surveyor, Custom House Arcade, Liverpool.

1876. Tayler, William Henry Osborne, Panteg Steel and Engineering Works, Panteg, near Pontypool.

1872. Teague, William, Mining Engineer, Tincroft Mines, Redruth.

1864. Tennant, Charles, The Glen, Innerleithen, near Edinburgh. (*Life Member.*)

1877. Thom, William, Messrs. W. and I. Yates, Canal Foundry, Blackburn.

1867. Thomas, Joseph Lee, 16 Holland Road, Kensington, London, W.

1864. Thomas, Thomas, 19 The Parade, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1857. Thompson, Robert, Standish, near Wigan.

1862. Thompson, William, Spring Gardens Engine Works, Newcastle-on-Tyne.

1875. Thoms, George Eastlake, Borough Engineer, Town Hall, Wolverhampton.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow.

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1877. Thornton, Frederick William, Hull Hydraulic Power Works, Machell Street, Hull.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.

1875. Thwaites, William Henry, Messrs. Thwaites and Carbutt's, Vulcan Iron Works, Thornton Road, Bradford.

1862. Tolmé, Julian Horn, 1 Victoria Street, Westminster, S.W.

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co.'s, Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Chapel Street Works, Edgware Road, London, N.W.

1867. Tonks, Edmund, Brass Works, Moseley Street, Birmingham.

1876. Trevithick, Richard Francis, Locomotive Engineer, Central Argentine Railway, Rosario, Argentine Republic.

1865. Trow, John James, Messrs. William Trow and Sons, Union Foundry, Wednesbury.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Holyhead Road, Wednesbury.

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich.

1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham.

1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.

1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W.

1874. Twibill, Joseph, Engineer and Ironfounder, Barrack Street, Tatton Street, Chester Road, Manchester.

1856. Tyler, Sir Henry Wheetley, K.C.B., Wivenhoe Hall, Colchester.

1877. Tylor, Joseph John, 4 Storey's Gate, Westminster, S.W.

1875. Unsworth, Thomas, Leicester Works, Dutton Street, Strangeways, Manchester.

1862. Upward, Alfred, 8 Queen Anne's Gate, Westminster, S.W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of John Maclachlan, 15 Hamilton Street, Greenock).

1872. Usher, Thomas, Messrs. Reay and Usher, South Hylton Iron Works, Sunderland.

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1875. Wailes, John William, Panteg Steel and Engineering Works, Panteg, near Pontypool.

1865. Wainwright, William, Midland Railway, Carriage and Wagon Department, Derby.

1863. Wakefield, John, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Dublin.

1873. Waldenström, Eric Hugo, Manager, Broughton Copper Co.'s Works, Broughton Road, Manchester.

1872. Walker, Alexander, Locomotive Superintendent, Cambrian Railways, Oswestry.

1870. Walker, Alfred, Albion Iron Works, Aldwark, York.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds.

1864. Walker, Bernard Peard, Eagle Foundry, Broad Street, Birmingham.

1867. Walker, Charles Clement, Midland Iron Works, Donnington, near Newport, Shropshire; and Lilleshall Old Hall, near Newport, Shropshire.

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan.

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, Oxford Street, Birmingham.

1875. Walker, William, Mining Engineer, Saltburn-by-the-Sea.

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1865. Waller, George Arthur, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross Stephens and Walpole, North Wall Iron Works, Dublin.

1877. Walton, James, 292 Strand, London, W.C.

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1877. Wardell, Stuart Crawford, Mining Engineer, Birchwood and Tibshelf Collieries, Alfreton; and Doe Hill House, near Alfreton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham.

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1874. Warner, Edward, Messrs. Woods Cocksedge and Co., Suffolk Iron Works, Stowmarket.

1874. Wass, John William, 13 Harrison Place, Newcastle-on-Tyne.

1867. Watkin, William John Laverick, Mining Engineer, Pemberton Colliery, near Wigan.

1862. Watkins, Richard, Messrs. Seaward and Co., Canal Iron Works, Millwall, London, E.

1866. Watson, Robert, Engineer, Brereton and Hayes Collieries, near Rugeley.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., 29 Tyrrel Street, Bradford.

1862. Webb, Francis William, Locomotive Superintendent, London and North Western Railway, Crewe.

1872. Welch, Edward John Cowling, Stephenson Boiler and Forge Co., Failsworth, Manchester.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1876. West, Henry Hartley, Chief Surveyor, Underwriters' Registry for Iron Vessels, 13A Exchange Buildings, Liverpool.

1871. West, Henry Joseph, Stamford Works, 133 Great Suffolk Street, London, S.E.

1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.

1877. Western, Charles Robert, Messrs. Western & Co., Victoria Works, Belvedere Road, Lambeth, London, S.E.

1877. Western, Maximilian Richard, Messrs. Western and Co., Victoria Works, Belvedere Road, Lambeth, London, S.E.

1862. Westmacott, Percy Graham Buchanan, Sir William G. Armstrong and Co., Elswick Engine Works, Newcastle-on-Tyne.

1867. Weston, Thomas Aldridge, care of The Yale Lock Manufacturing Company, Stamford, Connecticut, United States.

1867. Wheatley, Thomas, Manager, Wigtownshire Railway, Wigtown, Wigtownshire.

1856. Wheeldon, Frederick R., Highfields Engine Works, Bilston; and 16 Waterloo Road South, Wolverhampton.

1872. Whieldon, William, Collinge Engineering Works, 190 Westminster Bridge Road, Lambeth, London, S.E.

1874. White, Henry Watkins, The Park, Cosham, Hants.

1864. White, Isaias, Messrs. Portilla and White, Engineers and Iron Ship Builders, Seville, Spain: (or care of Isaac White, Pontardulais, Llanelly.)

1868. Whitehead, Peter Ormerod, The Elms, 26 Seedley Road, Pendleton, Manchester.

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1859. Whitham, James, Perseverance Iron Works, Kirkstall Road, Leeds.

1863. Whitley, Joseph, New British Iron Works, Corngreaves, near Birmingham.

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds.

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1866. Whitwell, Thomas, Thornaby Iron Works, Stockton-on-Tees.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., 44 Chorlton Street, Portland Street, Manchester; and The Firs, Fallowfield, Manchester.

1859. Wickham, Lamplugh Wickham, Low Moor Iron Works, near Bradford.

1868. Wigram, Reginald, Messrs. John Fowler and Co.'s Steam Plough and Locomotive Works, Leeds.

1867. Wilkes, John, Bordesley Tube Mills, Liverpool Street, Birmingham.

1868. Wilkieson, Major-General Charles Vaughan, R.E., care of Messrs. Richardson and Co., 23 Cornhill, London, E.C.

1877. Wilkinson, Robert, Engineer, Lima Water Works, Lima, Peru.

1874. Williams, David, Manager, Pontypool Iron and Tinplate Works, Pontypool.

1865. Williams, Edward, Cleveland Lodge, Middlesbrough.

1872. Williams, Sir Frederick Martin, Bart., M.P., Perran Foundry, Goonvrea, Perranarworthal, Cornwall. (*Life Member.*)

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1859. Williams, Richard Price, 9 Great George Street, Westminster, S.W.

1869. Williams, Walter, Wednesbury Oak Iron Works, Tipton.

1873. Williams, William Lawrence, Manager, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1870. Willman, Charles, 3 Cleveland Terrace, Middlesbrough.

1872. Wilson, Alfred, Messrs. Howson and Wilson, 2 Exchange Place, Middlesbrough.

1856. Wilson, Edward, 9 Dean's Yard, Westminster, S.W.

1859. Wilson, George, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.

1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.

1863. Wilson, John Charles, Avonside Engine Works, St. Philip's, Bristol.

1857. Wilson, Robert, F.R.S.E., Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.

1872. Wilson, Stephen, Engineer, Wearmouth Colliery, Sunderland.

1873. Wilson, Thomas Sipling, Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Hunslet Road, Leeds; and 52 Sparsholt Road, Crouch Hill, London, N.

1867. Winby, Frederick Charles, Cardiff.

1872. Winn, Charles William, 30 Easy Row, Birmingham.

1872. Winstanley, Robert, Jun., Mining Engineer, Lancaster Avenue, Fennel Street, Manchester.

1859. Winter, Thomas Bradbury, 53 Moorgate Street, London, E.C.

1872. Wise, William Lloyd, Chandos Chambers, Buckingham Street, Adelphi, London, W.C.

1872. Withinshaw, John, Birmingham Engine Works, Wiggin Street, Icknield Port Road, Birmingham; and The Limes, Noel Road, Edgbaston, Birmingham.

1871. Withy, Edward, Messrs. Withy and Co., Middleton Iron Shipbuilding Yard, Hartlepool.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1876. Wood, Thomas, Mining Engineer, North Hetton Collieries, Fence Houses.

1873. Woodhead, John Proctor, 16 Tib Lane, Manchester.

1851. Woodhouse, John Thomas, Mining Engineer, Midland Road, Derby.

1874. Worsdell, Thomas William, London and North Western Railway, Locomotive Department, Crewe.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N.

1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.

1860. Worthington, Samuel Barton, Resident Engineer, London and North Western Railway, Victoria Station, Manchester; and 12 York Place, Oxford Road, Manchester.

1866. Wren, Henry, Messrs. Wren and Hopkinson, London Road Iron Works, Manchester.

1870. Wright, George Benjamin, Goscote Iron Works, near Walsall.

1876. Wright, James, Messrs. Ashmore and While's, Hope Iron Works, Bowesfield, Stockton-on-Tees.

1867. Wright, John Roper, Panteg Steel and Engineering Works, Panteg, near Pontypool.

1867. Wright, John Turner, Universe Rope Works, Garrison Street, Birmingham.

1859. Wright, Joseph, Metropolitan Railway Carriage and Wagon Company, Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton.

1863. Wright, Owen, Broadwell Forge, Oldbury, near Birmingham.
1871. Wright, William, Lostwithiel.
1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.
1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.
1877. Wyvill, Frederic Christopher, Messrs. Pollock and Pollock, Longclose Works, Newtown, Leeds.

1873. Young, Charles Frederic Trelawny, 112 St. Donatt's Road, New Cross, London, S.E.
1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.
1861. Yule, William, 80 Brown Street, Dalmarnock Road, Glasgow.

HONORARY LIFE MEMBERS.

1865. Downing, Samuel, LL.D., Trinity College, Dublin; and 4 The Hill, Monkstown, near Dublin.
1867. Morin, General Arthur, Director, Conservatoire National des Arts et Métiers, Paris.
1867. Tresca, Henri, Engineer Sub-Director, Conservatoire National des Arts et Métiers, Paris.

ASSOCIATES.

1865. Barker, Frederick, Leeds Iron Works, Leeds.
1873. Barry, William Henry, 7 Birchin Lane, London, E.C.
1867. Blinkhorn, William, London and Manchester Plate Glass Works, Sutton, St. Helen's.
1866. Crossley, John, British Plate Glass Works, Ravenhead, near St. Helen's.
1867. Dewhurst, John Bonny, Bellevue Cotton Mills, Skipton.
1863. Forster, George Emmerson, Contractor's Office, Washington, County Durham.
1865. Gössell, Otto, 41 Moorgate Street, London, E.C.
1874. Hardcastle, Robert Anthony, Clarence Iron Works, Leeds.
1874. Hurman, James, Traffic Superintendent, Taff Vale Railway, Cardiff; and 22 Albert Terrace, Charles Street, Cardiff.
1858. Lawton, Benjamin C., Corbridge, Northumberland.
1859. Leather, John Towlerton, Leventhorpe Hall, near Leeds. (*Life Associate.*)
1865. Longsdon, Alfred, 2 Crown Buildings, Queen Victoria Street, London, E.C.
1860. Manby, Cordy, Messrs. Moore and Manby, Castle Street, Dudley.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield.
1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C.
1865. Parry, David, Leeds Iron Works, Leeds.
1864. Parsons, Charles T., Ann Street, Birmingham.
1874. Pepper, Joseph Ellershaw, Monkbridge Iron Works, Leeds.
1877. Render, Frederick, Crown Corn Mills, Stanley Street, Salford, Manchester.
1875. Schofield, Christopher J., Clayton, near Manchester.
1864. Tennant, John, St. Rollox Chemical Works, Glasgow. (*Life Associate.*)
1869. Varley, John, Farnley Iron Works, Leeds.
1877. Vial, Enrique de, Muelle No. 14, Santander, Spain: (or care of Messrs. Alexander Bell and Sons, 8 Finch Lane, London, E.C.)
1875. Wasalekar, Nanaji Narayan, Apna Cottage, Surat, India.
1858. Waterhouse, Thomas, Claremont Place, Sheffield. (*Life Associate.*)

GRADUATES.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)
1872. Armstrong, Thomas, Great Western Railway, Carriage Department, Swindon.
1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.
1874. Browne, Tomyns Reginald, Vulcan Foundry, Newton-le-Willows, Lancashire.
1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.
1875. Dawson, Edward, Haswell Colliery, Fence Houses.
1873. Dobson, Richard Joseph Caistor, Sugar Fabric Trankil, Pattie, Japara, Java: (or care of R. C. Lowndes, Rice House, West Derby, Liverpool.)
1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street, Summer Lane, Birmingham.
1873. Edmunds, John Sharp Wilbraham, Hampton-in-Arden, near Birmingham.
1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.
1877. Heaton, Arthur, Messrs. Heaton and Dugard's Metal and Wire Works, Shadwell Street, Birmingham.
1874. Hedley, Henry, Coppa Colliery, near Mold, Flintshire.
1874. Hedley, Thomas, Trinity Terrace, Derby.
1867. Holland, George, Vulcan Foundry, Newton-le-Willows, Lancashire.

1877. Jeffreys, Edward Homer, Low Moor Iron Works, near Bradford.
1877. Kortright, Lawrence Moore, 18 Market Street, Holyhead.
1868. Mappin, Frank, Messrs. Thomas Turton and Sons' Sheaf Works, Sheffield.
1867. Mayhew, Horace, Mining Engineer, Hindley House, near Wigan.
1867. Mitchell, John, Swaithe Colliery, Barnsley.
1868. Moor, William, Jun., Engelholm, Sweden.
1872. Napier, Robert Twentyman, 22 Blythswood Square, Glasgow.
1876. Owen, George Charles Mickleburgh, Messrs. Sharp Stewart and Co.'s, Atlas Works, Manchester.
1867. Pearson, John Edward, Golborne Park, near Newton-le-Willows, Lancashire.
1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.
1874. Rankeilor, William Collis, Wednesbury Oak Iron Works, Tipton.
1875. Sheppard, Herbert Gurney, Messrs. James Watt and Co.'s Works, Soho Foundry, near Birmingham.
1873. Simpson, Alfred, Denmark House, Alexandra Road, St. John's Wood, near Hull.
1877. Spielmann, Marion Harry, 16 Linden Gardens, Kensington Gardens, London, W.
1874. Stephenson, Joseph, Chatterley Iron Works, Tunstall, near Stoke-upon-Trent.
1874. Taylor, Arthur, Pontgibaud Lead Works, Puy de Dôme, France; and 6 Queen Street Place, Upper Thames Street, London, E.C.
1875. Walker, Arthur Henry, Guild Hall Chambers, Cardiff.
1877. Whitelock, William Thomas Grant, Bowling Iron Works, near Bradford.
1868. Wicksteed, Joseph Hartley, Well House Foundry, Meadow Road, Leeds.

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PROCEEDINGS.

JANUARY 1877.

The THIRTIETH ANNIVERSARY MEETING of the Members was held in the lecture theatre of the Midland Institute, Birmingham, on Thursday, 25th January, 1877; THOMAS HAWKSLEY, Esq., President, in the Chair.

The Minutes of the last General Meeting were read and confirmed.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF COUNCIL.

1877.

The Council now beg to lay their Annual Report before the Meeting on this occasion of the Thirtieth Anniversary of the Institution.

The roll of the Institution shows that at the end of last year 1876 there were

Members	Hon. Life Members	Associates	Graduates	Total
977	3	30	31	1041

as compared with

Members	Hon. Life Members	Associates	Graduates	Total
949	3	32	34	1018

at the corresponding period of the previous year, showing an effective increase of 23. This increase arises as follows.

There have been elected within the year

Members	Associates	Graduates	Total
60	0	3	63

there have been lost by deceases in 1875

Members	Associates	Graduates	Total
14	0	0	14

and there have been lost by resignations or by removal from the register in 1876

Members	Associates	Graduates	Total
21	2	3	26

With respect to the Financial position, the appended Balance Sheet will show that including the balance of £11,178 2*s.* 7*d.* from the previous year, there has been a total credit of £14,618 19*s.* 3*d.*; and that the expenses have been £2,674 13*s.* 6*d.*, leaving a balance in favour of the Institution amounting to £11,944 5*s.* 9*d.* This balance it will be seen is £766 3*s.* 2*d.* in excess of that with which the year 1876 was begun, and thus the expenses of the year 1876 have been £766 3*s.* 2*d.* less than the true income of that year. The greater portion of the present balance is invested in £6000 London and North Western Railway 4 per cent. debenture stock, £2200 North Eastern Railway 4 per cent. debenture stock, £1800 Midland Railway 4 per cent. debenture stock, and £1000 Great Western Railway 4 per cent. debenture stock, all registered in the names of Mr. Frederick J. Bramwell, Mr. Edward A. Cowper, and Mr. John Ramsbottom, as trustees on behalf of the Institution. The Finance Committee have examined and checked the receipts and payments of the Institution for the past year, and report that the appended Abstract of Receipts and Expenditure rendered by the Treasurer is correct.

(*See Abstract appended.*)

The following Deceases of Members of the Institution have occurred during the past year:—

Charles F. Beyer, ... Manchester.
William Bouch, ... Darlington.
William Tarleton Bury, ... Sheffield.
James Clark, ... Leeds.
Henry Dübs, ... Glasgow.
Joseph Hall, ... Graz, Styria.

EVAN LEIGH, ...	Manchester.
ROBERT NAPIER, ...	Glasgow.
JOHN HENRY NYE, ...	Paris.
JOSEPH PHILIP RONAYNE, M.P., ...	Queenstown.
CHARLES DYKE TAYLOR, ...	Falmouth.
FALKLAND SAMUEL THORNTON, (Associate) . . .	Birmingham.
EDWARD TOMKINS, ...	Buxton.
ARTHUR JOHN WHALLEY, ...	Truro.

Prominent among these were Mr. Robert Napier, Past-President, and Mr. Charles F. Beyer, one of the founders of the Institution. At the Summer Meeting their deaths were officially announced, and a resolution was passed expressive of the deep regret felt for the loss of these two Members, and of sincere sympathy with their relatives.

The following Donations to the Library of the Institution have been received during the past year, for which the Council have the pleasure of expressing their thanks to the Donors. They trust the Members generally will promote the formation of a good collection of Engineering Books, Drawings, and Models or Specimens of interest in the Institution, for the purpose of reference by the Members personally or by correspondence; and Members are requested to present copies of their Works to the Library of the Institution.

LIST OF DONATIONS TO THE LIBRARY.

Theory of the Flow of Water in Open Channels, by Robert Gordon; from the author.

Discussion of a new Formula for the Flow of Water in Open Channels, by Robert Gordon; from the author.

Reports on the Drainage of Dudley, by Henry J. Marten and F. C. Stileman; from the authors.

Report on the 24-in. Bore-hole at Gosford, by Henry J. Marten; from the author.

Geological Report on Londonderry and parts of Tyrone and Fermanagh, by J. E. Portlock; from the Royal School of Mines.

Mineral Statistics of the United Kingdom, by Robert Hunt; from the Royal School of Mines.

Topographical Survey of the Adirondack Wilderness of New York, by Verplanck Colvin; from the author.

Evidence given in the Link Motion case; from Mr. Edward Woods.

Designing of Valve Gearing, by E. J. Cowling Welch; from the author.

Designing of Belt Gearing, by E. J. Cowling Welch; from the author.

On recent arrangements of Continuous Brakes, by St. John V. Day; from the author.

On Indicators of Speed, by A. Madamet; from the author.

Notes on the model of Newcomen's Steam Engine, by Thomas Lidstone; from the author.

Lectures on Iron Fortifications, by Col. Inglis; from the School of Military Engineering.

Street Pavements, by G. J. Crosbie Dawson; from the author.

Jubilee Memorial of the Railway System, by J. S. Jeans; from Mr. C. H. Bowes.

List of Chinese Lighthouses, Lightvessels, Buoys and Beacons for 1876; from Mr. David M. Henderson.

Financial Statement of the Colonial Treasurer of New South Wales.

Proceedings of the French Institution of Civil Engineers; from the Institution.

Journal of the French Society for the Encouragement of National Industry; from the Society.

Journal of the Marseilles Scientific and Industrial Society; from the Society.

Journal of the Hannover Architect and Engineer's Society; from the Society.

Journal of the Saxon Society of Engineers; from the Society.

Journal of the Norwegian Polytechnic Society; from the Society.

Transactions of the American Society of Civil Engineers; from the Society.

Transactions of the American Society of Mining Engineers; from the Society.

Smithsonian Institution Annual Report; from the Institution.

Proceedings and Journal of the Asiatic Society of Bengal: from the Society.

Proceedings of the Institution of Civil Engineers; from the Institution.

Transactions of the North of England Institute of Mining and Mechanical Engineers; from the Institute.

Proceedings of the South Wales Institute of Engineers; from the Institute.

Transactions of the Institution of Engineers in Scotland; from the Institution.

Journal of the Iron and Steel Institute; from the Institute.

Journal of the Society of Telegraph Engineers; from the Society.

Transactions of the Society of Engineers; from the Society.

Transactions of the Chesterfield and Derbyshire Institute of Engineers; from the Institute.

Proceedings of the Cleveland Institution of Engineers; from the Institution.

Proceedings of the Royal Society of London; from the Society.

Transactions of the Institution of Naval Architects; from the Institution.

Transactions of the Institution of Surveyors; from the Institution.

Journal of the Royal United Service Institution; from the Institution.

Proceedings of the Royal Artillery Institution; from the Institution.

Journal of the Royal Agricultural Society of England; from the Society.

Report of the British Association for the Advancement of Science; from the Association.

Memoirs of the Literary and Philosophical Society of Manchester; from the Society.

Proceedings of the Scientific and Mechanical Society of Manchester; from the Society.

Report of the Royal Cornwall Polytechnic Society; from the Society.

Transactions of the Royal Scottish Society of Arts; from the Society.

Proceedings of the Philosophical Society of Glasgow; from the Society.

Journal of the Society of Arts; from the Society.

Records of Steam Boiler Explosions from 1866 to 1874, by Edward B. Marten; from the author.

Report of the Manchester Steam Users' Association for the Prevention of Steam Boiler Explosions; from Mr. Lavington E. Fletcher.

Report of the National Boiler Insurance Company; from Mr. Henry Hiller.

Report of the Midland Steam Boiler Inspection and Assurance Association; from Mr. Edward B. Marten.

The Engineer; from the Editor.

Engineering; from the Editor.

Iron; from the Editor.

The Mining Journal; from the Editor.

The Railway Record; from the Editor.

In the course of 1876 the Meetings held were the Anniversary Meeting, the London Meeting, the Summer Meeting, and the Manchester Autumn Meeting. Two days were devoted at the Spring and Summer Meetings to the reading and discussion of Papers, making six days in all thus occupied; and at the meetings several valuable and important Papers were contributed, which led to useful practical discussions. The list of Papers is as follows:—

On the Ultimate Capacity of Blast Furnaces; by Mr. Charles Cochrane. (Adjourned Discussion.)

On the mode of Erection of the large Iron Girder Railway Bridge over the River Dal in Sweden; by Mr. Edward Hutchinson.

On the Lancashire Boiler, its Construction, Equipment, and Setting; by Mr. Lavington E. Fletcher.

Description of the Ogi Paper Mill, Japan; by Mr. William Anderson.

On the Yield of Wells sunk in the Chalk in the central portion of the London Basin; by Mr. Edward Easton.

On Dynamometers, Friction Brakes, and other Testing Apparatus, belonging to the Royal Agricultural Society of England; by Mr. William E. Rich.

On Mechanical Puddling; by Mr. T. Russell Crampton.
On the McCarter Condenser without Air-pump for steam engines; by Mr. Francis Preston.
On the Frisbie Mechanical Fire-Feeder and Grate for boilers and furnaces; by Mr. Bernard P. Walker.
On the Open Spray Tuyere, and other Blast-Furnace Tuyeres; by Mr. Francis H. Lloyd.
On Rope Gearing for the Transmission of large Power in mills and factories; by Mr. James Durie.

The attendances at the Meetings were, at the Anniversary Meeting 57 members and 12 visitors, at the Spring Meeting 87 members and 21 visitors, at the Autumn Meeting 69 members and 37 visitors.

The Summer Meeting was held in Birmingham, and the attendance was 144 members and 47 visitors. Excursions were made to several places of interest, including the Small Arms Factory at Smallheath, the Screw Works at Smethwick, the Needle Works at Redditch, the Birmingham Corporation Sewage Works, and the new Thick-Coal Workings at Lye Cross and Sandwell.

The Council have pleasure in announcing that the General Index to the Institution Proceedings, and the Library Catalogue, are completed; also that the reprinting of the Proceedings which were out of print is in progress, and the members will thus be enabled to complete their sets of Proceedings from the commencement.

The President, Vice-Presidents, and five of the Members of the Council in rotation, go out of office this day, according to the Rules of the Institution; and the ballot taken at the present meeting will show the election of the Officers and Council for the ensuing year.

SUBJECTS FOR PAPERS.

Steam Engine Boilers, particulars of construction—form and extent of heating surface—extent of water surface—relation of grate surface to heating surface, and heating surface to fuel consumed—relative value of radiant surface and flue surface in effect and economy—consumption of fuel—evaporation of water—pressure of steam—density and heat of steam—superheated steam, simple or mixed with common steam—combined air and steam—safety valves—water gauges—explosion of boilers, and means of prevention—strength and proportions of riveted joints, single and double riveting—welded joints—comparative strength of drilled and punched plates in iron and in steel—effects of heat on the metal of boilers, low-pressure and high-pressure—steel boilers—cast-iron boilers—welded boilers—small water-space boilers for specially high pressures—incrustation of boilers, and means of prevention—corrosion of boilers, and means of prevention—effects of surface condensers on the metal of boilers—evaporative power and economy of different kinds of fuel; coal, wood, charcoal, peat, coke, and artificial fuel—mechanical firing, movable grates and smoke-consuming apparatus, facts to show the best plan, and results of working—plans for heating feed-water—mode of feeding—use of injector—circulation of water—self-acting feeding apparatus.

Steam Engines—expansive force of steam, and best means of using it—effect of steam jackets—power obtained by various plans—comparison of double and single-cylinder engines—combined engines—compound-cylinder engines—comparative advantages of direct-acting and beam engines—horizontal and vertical engines—condensing and non-condensing engines—construction and particulars of working of injection and surface condensers—ejector condenser—air-pumps—piston speed—pistons, slide-valves, and other valves—governors—throttle valves—bearings, &c.—improved expansion gear—expansion gear controlled by governor—indicator diagrams from engines, comparison of these diagrams with dynamometer experiments, with details of useful effect, consumption of fuel, &c.—contributions of indicator diagrams for reference in the Institution.

PUMPING ENGINES, particulars of various constructions—Cornish engines, beam engines with crank and flywheel, direct-acting engines with and without flywheel—size of steam cylinder and degree of expansion—number and size of pumps, and strokes per minute—speed of piston—pressure upon pump—effective horse power and duty—comparison of double-acting and single-acting pumping engines—indicator diagrams from pumps—construction of pumps—plunger pumps—bucket pumps—rotary and centrifugal pumps—details of different pump valves—india-rubber valves, durability and results of working—diagrams of lift of valves—application of pumps—fen-draining engines—comparative advantages of scoop wheels and centrifugal pumps, lifting trough, &c.—sewage pumping engines—details of pit work of pumping engines in mines.

BLAST ENGINES, best kind of engine—details of construction—pressure of blast, and means of regulation—construction of valves—improvements in blast cylinders—rotary blowing machines—indicator diagrams from steam cylinder, blast cylinder, and blast main.

MARINE ENGINES, power of engines in proportion to tonnage—dimensions and form of vessel—different constructions of engines, compound-cylinder engines, trunk engines, oscillating engines—three-cylinder engines—use of steam jackets—dynamical effect compared with indicator diagrams—comparative economy and durability of different boilers, tubular boilers, flat-flue boilers, &c.—brine pumps, and means of preventing deposit—surface condensers—salinometers—weight of machinery, and boilers—speed obtained in different steamers, with particulars of construction of engines—screw propellers, particulars of different kinds, improvements in form and position, number of arms, material, means for unshipping, bearings, horse power applied, speed obtained, section of vessel—reaction propellers—governors and storm governors.

ROTARY ENGINES, particulars of construction and practical application—details of results of working.

LOCOMOTIVE ENGINES, particulars of construction, details of experiments, and results of working—economy of fuel—relative value and evaporative duty of coke and coal—consumption of smoke—use of wood—construction of spark arresters—heating surface, length and diameter of tubes—material of tubes—experiments on size of tubes and blast-pipe—construction of pistons, valves, expansion gear, &c.—balanced slide-valves—indicator diagrams—expenses of working and repairs—means of supplying water to tenders—locomotives for steep gradients and sharp curves—steam breaks, counterpressure steam break—vacuum breaks—distribution of weight on wheels.

AGRICULTURAL ENGINES, details of construction and results of working—duty obtained—application of machinery and steam power to agricultural

purposes — barn machinery — field implements — ploughing engines — traction engines, particulars of performance and cost of work done.

STEAM ROAD ROLLERS, particulars and results of working.

HOT-AIR ENGINES—engines worked by gas, or explosive compounds—electro-magnetic engines—particulars and results.

HYDRAULIC ENGINES, particulars of application and working—pressure of water—construction and arrangement of valves, relief valves—accumulator—hydraulic machinery—construction of joints—hydraulic rams.

WATER WHEELS, particulars of construction and dimensions—form and depth of buckets—head of water, velocity, percentage of power obtained—turbines, construction and practical application, power obtained, comparative effect and economy—transmission of power to distant points.

WIND MILLS, particulars of construction—number of sails, surface and form of sails—velocity, and power obtained—average number of days' work per annum.

CORN MILLS, particulars of improvements—power employed—application of steam power—results of working with an air-blast and ring stones—crushing by rolls before grinding—stone-dressing machinery.

SUGAR MILLS, particulars of construction and working—results of application of the hydraulic press in place of rolls—application of steam and water for extracting the last portion of saccharine matter — construction and working of evaporating pans.

OIL MILLS, facts relating to construction and working, by stampers, by screw presses, and by hydraulic presses—particulars of crushing rollers and edge stones.

COTTON MILLS, information respecting the construction and arrangement of the machinery—power employed, and application of power—cotton presses, mode of construction and working, power employed—improvements in opening, carding, spinning, and winding machinery, &c.

CALICO-PRINTING AND BLEACHING MACHINERY, particulars of improvements.

WOOL MACHINERY, carding, combing, roving, spinning, &c.

FLAX MACHINERY, manufacture of flax, china grass, and other fibrous materials, both in the natural length of staple and when cut.

WEAVING MACHINERY, for manufacture of different materials—improvements in looms, &c.

LACE MACHINERY, particulars of improvements.

KNITTING MACHINERY, worked by hand or by power — particulars of improvements.

ROPE-MAKING MACHINERY—hemp and wire ropes, comparative strength, durability, and cost—steel wire ropes—transmission of power by ropes, percentage of loss, distance, wear of ropes, &c.

SAW MILLS, particulars of construction—mode of driving—power employed—particulars of work done—best speeds for vertical and circulars saws—form

of saw teeth—saw mills for cutting ship timbers—veneer saws—endless band saws—saw sharpeners.

WOOD-WORKING MACHINES, morticing, dovetailing, planing, rounding, and surfacing—copying machinery.

STONE-WORKING MACHINERY — cutting, planing, turning, and polishing machines.

GLASS MACHINERY — manufacture of plate and sheet glass—grinding and polishing machinery—construction of melting furnaces, annealing kilns, &c.

LATHES, PLANING, BORING, DRILLING, SLOTTING, AND SHAPING MACHINES, &c., particulars of improvements—description of new self-acting tools—engineers' tools—files and file-cutting machinery.

ROLLING MILLS, improvements in machinery for making iron and steel—mode of applying power—use of steam hammers—piling of iron—plates—fancy sections—arrangement and speed of rolls—length of bar rolled—manufacture of rolled girders—rolling of armour plates—reversing rolling mills.

HAMMERS, improvements in construction and application—steam hammers—friction hammers—air hammers—tilt hammers.

RIVETING, PUNCHING, AND SHEARING MACHINES, worked by steam or hydraulic pressure—direct-acting and lever machines—portable machines—rivet-making machines—comparative strength of hand and machine riveting—plate-bending and flanging machines.

STAMPING AND COINING MACHINERY, particulars of improvements, &c.

LOCKS, and lock-making machinery—iron safes.

PAPER-MAKING AND PAPER-CUTTING MACHINES, new materials and results.

PRINTING MACHINES, particulars of improvements, &c.—machines for printing from engraved surfaces—type composing and distributing machines.

HYDRAULIC PRESSES, facts relating to the best construction, means of working, and application—economical limit of pressure.

FIRE ENGINES, hand and steam, ditto ditto ditto.

SLUICES AND SLUICE COCKS, worked by hand or by hydraulic power, ditto.

CRANES—steam, hydraulic, and pneumatic cranes—travelling cranes.

LIFTS for raising railway wagons—hoists for warehouses, blast-furnaces, &c.—safety apparatus.

TOOTHED WHEELS, best construction and form of teeth—results of working—strength of iron and wood teeth—moulding by machinery—cutting teeth by machinery.

DRIVING BELTS AND STRAPS, best make and material, leather, gutta-percha, vulcanised india-rubber, rope, wire, chain, &c.—comparative durability, adhesion, and results of working—power communicated by certain sizes—frictional gearing, construction and driving power obtained—friction clutches—shafting and couplings.

DYNAMOMETERS, construction, application, and results of working.

PRESSURE GAUGES, for steam and water—varieties of construction—durability and results of working—speed indicators for vessels and trains.

DECIMAL MEASUREMENT—application of decimal system of measurement to mechanical engineering work, drawing and construction of machinery, manufactures, &c.—construction of measuring instruments, gauges, &c.

STRENGTH OF MATERIALS—facts relating to experiments, and general details of testing—influence of temperature on strength.

GIRDERS OF CAST AND WROUGHT IRON, particulars of different constructions, and experiments on them—rolled girders—best forms and proportions of girders for different purposes—best mixture of metal—mixtures of wrought iron with cast.

DURABILITY OF TIMBER of various kinds—best plans for seasoning and preserving timber and cordage—results of various processes—comparative durability of timber in different situations—experiments on actual strength of timber.

CORROSION OF METALS by salt and fresh water, and by the atmosphere, &c.—facts relating to corrosion, and best means of prevention—means of keeping ships' bottoms clean—galvanic action, nature and preventives.

ALLOYS OF METALS, facts relating to different alloys.

FRICTION OF VARIOUS BODIES, facts relating to friction under ordinary circumstances—facts on increase of friction by reduction of surface in contact—friction of iron, brass, copper, tin, wood, &c.—proportion of weight to rubbing surface—best forms of journals, and construction of axleboxes—wood bearings—water axleboxes—lubrication, best materials, means of application, and results of practical trials—best plans for oil tests—friction breaks—friction of ropes.

ROOFS, particulars of construction for different purposes—cast-iron, wrought-iron, timber, &c.—best construction, form, and materials—details of large roofs, and cost—durability in various climates and situations—comparative cost, weight, and durability.

FIRE-PROOF BUILDINGS, particulars of construction—most efficient plan—results of trials—means of rendering timber &c. incombustible.

CHIMNEY STACKS of large size—particulars, form, mode of building, cheapest construction, &c.—force of draught, and temperature of current.

BRICKS, manufacture, durability, and strength—hollow bricks, fire bricks, and fire clay—perforated bricks, cost of manufacture, and advantages—dry-clay bricks—machines for brick-making—burning of bricks.

GAS WORKS, best form, size, and material for retorts—construction of retort ovens—quantity and quality of gas from different coals—oil gas, cheapest mode of making—water gas, &c.—improvements in purifiers, condensers, and gasholders—wet and dry gas-meters—self-regulating meters—pressure

of gas—gas-exhausters, construction and results of working—gas pipes, strength and durability, and construction of joints—proportionate diameter and length of gas mains, and velocity of the passage of gas—experiments on ditto, and on the friction of gas in mains, and loss of pressure—lighting railway trains with gas.

WATER WORKS, facts relating to—application of power, and economy of working—proportionate diameter and length of pipes—experiments on the discharge of water from pipes, and friction through pipes—incrustation in pipes, effect on delivery, and means of prevention or removal—strength and durability of pipes, and construction of joints—penetration of frost in different climates—relative advantages of stand pipes and air vessels—sluices and self-acting valves—relief valves—machinery for working sluices—water meters, construction and working.

WELL SINKING, AND ARTESIAN WELLS, facts relating to—boring tools, construction and mode of using.

TUNNELLING MACHINES, particulars of construction, and results of working.

COFFERDAMS AND PILING, facts relating to construction—cast-iron sheet piling.

PIERS, fixed and floating, and pontoons—particulars of construction.

PILE-DRIVING APPARATUS, particulars of improvements—use of steam power—particulars of working—weight of ram and height of fall, total number of blows required—vacuum piles—compressed air system—screw piles—pile shoes.

DREDGING MACHINES, particulars of improvements—application of dredging machines—power required and work done.

EXCAVATING MACHINES, construction and results of working.

DIVING BELLS AND DIVING DRESSES, facts relating to the best construction.

SUBAQUEOUS ENGINEERING, particulars of works.

LIGHTHOUSES, cast-iron and wrought-iron, ditto ditto.

SHIPS, iron and wood—details of construction—lines, tonnage, cost per ton—water ballast—iron and steel masts and yards, and wire-rope rigging—comparative strength and advantage of iron and wood ships—arrangements for docking and repairing ships—steering gear—application of steam and hydraulic power to steering—instruments to record rolling of ships and to ascertain stability.

GUNS, cast-iron, wrought-iron, and steel—manufacture and proof—rifling—shot and shells, cast-iron and steel, manufacture and proof.

SMALL ARMS, machinery for manufacture of rifles and cartridges, &c.—breech-loading mechanism.

BLASTING, facts relating to blasting under water, and blasting generally—use of gun-cotton, dynamite, &c.—effects produced by large and small charges of powder—arrangement of charges.

MINING OPERATIONS, facts relating to mining—modes of working and proportionate yield—coal-cutting machines—rock-drilling machines—

means of ventilating mines—use of ventilating machinery—safety lamps—lighting mines by gas—drainage of mines—sinking pits—mode of raising materials—safety guides—winding machinery—hauling arrangements underground and at surface—stone-breaking machines—mode of breaking, pulverising, and dressing various descriptions of ores—coal-washing machinery.

BLAST FURNACES, shape and size—consumption of fuel—yield and quality of metal—pressure of blast—economy of working—improvements in manufacture of iron—comparative results of hot and cold blast—increased temperature of blast—construction and working of hot-blast stoves—pyrometers—construction of tuyeres—means and results of application of waste gas from close-topped and open-topped furnaces—preparation of materials for furnace, and mode of charging.

PUDDLING FURNACES, best forms and construction—gas furnaces—application of machinery to puddling.

SMELTING FURNACES, for reduction of copper, tin, and lead ores, &c.—best construction and modes of working.

HEATING FURNACES, best construction—consumption of fuel, and heat obtained.

CUPOLAS, construction and proportions—improvements in means of blowing—results of working, and economy of fuel.

CONVERTING FURNACES, construction of furnaces—manufacture of steel—casehardening, &c.—converting materials employed.

SMITHS' FORGES, best construction—size and material—power of blast—hot blast, &c.—construction of tuyeres.

BLOWING FANS, best construction, form of blades, &c.—facts relating to power employed and percentage of effect produced—pressure and quantity of air discharged—size and construction of air mains.

VENTILATING FANS for mines—ventilating machines—mechanical ventilation and warming of public buildings.

FUEL, solid, powdered, liquid, gaseous.

COKE AND CHARCOAL, particulars of the best mode of making, and construction of ovens, &c.—open coking, mixtures of coal-slack and other materials—evaporative power of different varieties—peat, manufacture of compressed peat.

RAILWAYS—construction of permanent way—section of rails, and mode of manufacture—mode of testing rails—experiments on rails, deflection, deterioration, and comparative durability—material and form of sleepers, size, and distances—improvements in chairs, keys, and joint fastenings—permanent way for hot climates.

SWITCHES AND CROSSINGS, particulars of improvements, and results of working.

TURNTABLES, particulars of various constructions and improvements—engine turntables.

SIGNALS for stations and trains, and self-acting signals—interlocking apparatus for signals and points—switch locks.

ELECTRIC TELEGRAPHS, improvements in construction and insulation—coating of wires—underground and submarine cables—construction—laying and picking-up machinery.

RAILWAY CARRIAGES AND WAGONS, details of construction—proportion of dead weight.

BREAKS for carriages and wagons, best construction — self-acting breaks — continuous breaks—steam, air, and hydraulic breaks.

BUFFERS for carriages, &c., and station buffers—different constructions and materials.

COUPLINGS for carriages and wagons—self-acting couplings.

SPRINGS for carriages, &c.—buffing, bearing, and draw springs—range and deflection per ton—particulars of different constructions and materials, and results of working.

RAILWAY WHEELS, wrought-iron, cast-iron, and wood—particulars of different constructions, and results of working—comparative expense and durability—wrought-iron and steel tyres, comparative economy and results of working—mode of fixing tyres—manufacture of weldless tyres, and solid wrought-iron wheels.

RAILWAY AXLES, best description, form, material, and mode of manufacture—durability, and causes of fracture.

PREPARATION OF PAPERS.

The Papers to be written in the third person, on foolscap paper, on one side only of each page, leaving a clear margin of an inch width on the left edge. In the subjects of the papers, questions of patent right or priority of invention and extracts from printed publications are not admissible, except as references in a historical paper.

The Diagrams to be on a large scale and strongly coloured, so as to be clearly visible to the meeting at the time of reading the paper. Enlarged details to be added for the illustration of any particular portions, drawn full size or magnified, with the different parts strongly coloured in distinctive colours. Several explanatory diagrams drawn roughly to a large scale in dark pencil lines and strongly coloured are preferable to a few small-scale finished drawings. The scale of each diagram to be marked upon it.

The author of a Paper that has been accepted by the Council can, if he desires, have (subject to the approval of the Council) a reasonable amount of assistance from the Institution in preparing the Diagrams for the paper.

INSTITUTION OF MECHANICAL ENGINEERS.

ABSTRACT OF RECEIPTS AND EXPENDITURE,

For the year ending 31st December 1876.

Cr.				£	s.	d.
By Balance 31st Dec. 1875; Invested	10,188	16	2			
In Bank	839	6	5			
Cash in hand	150	0	0	11,178	2	7
,, Subscriptions from 42 Members in arrear . .				126	0	0
,, do. 846 Members for 1876 . .				2,538	0	0
,, do. 22 Associates do. . .				66	0	0
,, do. 29 Graduates do. . .				58	0	0
,, do. 6 Members in advance . .				18	0	0
,, do. 1 Life Member				30	0	0
,, Entrance Fees from 61 New Members				122	0	0
,, do. 3 New Graduates . . .				3	0	0
,, do. 3 Graduates transferred to Members . . .				3	0	0
,, Sale of Extra Reports				45	14	6
,, Interest; From Bank	14	0	2			
On £10,200 Stock at 4 p.c. one year, less income tax	404	3	6			
On £800 Stock at 4 p.c. 149 days, less income tax	12	18	6	431	2	2
				£14,618	19	3

Dr.				£	s.	d.
To Printing and Engraving Reports of Proceedings	965	7	11			
Less Authors' copies of Papers, repaid	23	7	6	942	0	5
,, Stationery, Binding, Printing of Circulars, &c.				91	13	2
,, Office Expenses, Clerks, and Petty Disbursements				127	13	11
,, Coal, Gas, and Water				33	2	0
,, Expenses of Meetings				127	9	2
,, Fittings and Repairs				22	5	0
,, Travelling Expenses				38	13	10
,, Parcels				3	4	11
,, Postages				118	4	10
,, Salaries				1,050	0	0
,, Insurance				2	10	0
,, Rent and Taxes				117	16	3
Balance 31st Dec. 1876; Invested	11,016	16	2			
In Bank	777	9	7			
Cash in hand	150	0	0	11,944	5	9
				£14,618	19	3

(Signed) CHARLES COCHRANE,
WALTER MAY, } Finance Committee.

25th January 1877.

MEMOIRS

OF MEMBERS DECEASED IN 1876.

CHARLES FREDERICK BEYER was born on 14th May 1813 at Plauen, Saxony, his parents being in humble circumstances and working at hand-loom weaving. After studying for four years in the polytechnic school at Dresden, he worked two years in a machine shop in Chemnitz; and in 1834 was commissioned by the Saxon Government to visit England and report upon the improvements in machinery, chiefly in regard to cotton spinning. In the following year he obtained an appointment as draughtsman in the works of Messrs. Sharp Roberts and Co., Manchester, where he speedily attracted the notice of Mr. Roberts, both as a mathematician and as a quick and true draughtsman. The firm about that time began to turn their attention to the manufacture of locomotive engines; and the carrying out of this branch of their business under Mr. Roberts' instructions being entrusted to Mr. Beyer, the foundation was laid of a high reputation for building locomotives, and a large number of distinctive character and excellent workmanship soon made their appearance upon various English and continental lines, which proved eminently satisfactory in their performance. In 1843 on the retirement of Mr. Roberts he became the mechanical head of the works, and continued in that position for ten years. In 1854 he joined Mr. Richard Peacock in establishing the large and successful locomotive works of Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester. In the designing of these new works, he so arranged the various sections of the works that they formed almost exact counterparts of one another, so far as the buildings were concerned, and admitted of the subsequent gradual expansion and enlargement of the whole

by the simple addition of other sections, without disturbing or altering the portions previously erected. In the production of most of the details of locomotive engines he designed and adapted many special tools, thereby at once improving the character and reducing the cost of the work done; and he brought to bear upon locomotive design an innate perception of mechanical fitness and a refined taste, that have given a distinctive stamp to his numerous works. He took an active interest in and gave valuable support to the extension and rebuilding of Owen's College, Manchester, having been early impressed with its importance from his familiarity with the successful working of German polytechnic schools, and he left a large bequest for the foundation and endowment of professorships of science at the College. He was one of the founders of the Institution, and a Vice-President for a number of years; and he contributed several papers to the proceedings. His death took place after a considerable time of failing health at his residence, Llantysilio Hall, Denbighshire, on 2nd June 1876 at the age of 63.

WILLIAM BOUCH was born in 1813, and after serving his time in the works of Messrs. Stephenson, Newcastle, went to Russia and became chief engineer on a vessel in the Russian navy, which position he occupied for several years. Returning to England in 1840, he was appointed Locomotive Superintendent of the Stockton and Darlington Railway, where he brought out several improvements connected with the locomotive engine. He held that position till the time of his death, which occurred at Weymouth on 19th January 1876 at the age of 62, after several months of failing health. He was also conjoint engineer with Mr. Hawksley of the Weardale and Shildon District Water Works and of the Consett Water Works; and in addition was a prominent member of various ironworks and engineering firms in the North of England. He became a Member of the Institution in 1858.

WILLIAM TARLETON BURY was born in Liverpool on 12th January 1835, being the youngest son of Edward Bury, engineer, of the

Clarence Foundry in that town. When about twenty years of age he went to Sheffield, where he devoted himself with great energy to the manufacture of steel and its various uses, and became chief director and manager of the firm of Messrs. Burys and Co., Regent Steel Works; this position he continued to occupy up to his death, which took place suddenly on 21st July 1876 in the 42nd year of his age. He became a Member of the Institution in 1873.

JAMES CLARK was born in Manchester on 8th April 1836; and after serving his apprenticeship as an engineer at the works of Messrs. W. and J. Galloway and Sons in Manchester, where his father was engaged as manager, he entered the works of Messrs. Beyer Peacock and Co. at Gorton, and was afterwards employed at Messrs. Whitworth and Co.'s and Messrs. Sharp Stewart and Co.'s works, Manchester. In 1860 he was engaged by Messrs. Fairbairn Kennedy and Naylor, Leeds, to represent their firm in engineering tools; and he continued there, with the exception of a short interval in 1866 and 1867, until the time of his death, which took place on 12th February 1876 at the age of 39. He became a Member of the Institution in 1862.

HENRY DÜBS was born at Guntersblum, Hesse Darmstadt, on 10th March 1816, and at the age of fourteen was apprenticed to turning and fitting at a small shop in Mayence; and in 1834 entered the machine works of Messrs. Reuleaux and Co., Aix-la-Chapelle, of which he became shop manager when about 21 years of age. In 1839 he came over to England to see the engineering works of this country, and after going through Messrs. Penn's manufactory in London went to Manchester, where he was for some time in the drawing office at Messrs. Sharp Roberts and Co.'s works. In 1842 he became manager at the Vulcan Foundry near Warrington, where he remained till 1857. After a short connection with the works of Messrs. Beyer Peacock and Co., Manchester, he went in 1858 to Glasgow, and became partner of Mr. W. M. Neilson, in connection with whom he designed and laid out the Hyde Park Locomotive Works at Springburn,

Glasgow, the first locomotive factory of importance in Scotland. In 1863 he began the plans for a locomotive manufactory of his own at Glasgow, and within one year of commencing operations the large works known as the Glasgow Locomotive Works were built and the first engine turned out of the shops. These works were entirely designed by himself, and they were practically complete from the first, no alterations from his drawings having been required. His great capacity for organising workmen and systematising work led to his becoming in 1874 managing director of the large works of the Steel Company of Scotland at Newton, near Glasgow. He was one of the original Members of the Institution at its formation in 1847. He died on 24th April 1876 in the 61st year of his age, after an illness of about six months.

EVAN LEIGH was born on 21st December 1810 at Ashton-under-Lyne, his father being an extensive cotton spinner in that town. At the age of twenty, having then taken the management of his father's mill, he introduced the coupling of the spinning mules and the "putting-up" motion, an invention which effected a reduction of 40 per cent. in the cost of spinning on the mules. About 1850 he retired from the business of cotton spinning, to enter upon the manufacture of machinery at Miles Platting, Manchester; and about the same time he invented the self-stripping carding engine. He also then invented the twin screw for steamers, which has since come into general use both in the mercantile service and in the navy. In 1856 he invented the loose-boss top roller, now universally adopted in cotton mills; and about the same time he erected and started the Junction Works at Miles Platting for the manufacture of machinery on a more extensive scale; from which he withdrew in 1869 and then commenced practice as a consulting engineer and exporter of machinery. In 1871 he published a large work upon "the Science of modern Cotton Spinning," giving the results of nearly half a century of practical experience of mills and mill machinery, which has an extensive circulation both in Europe and in America. In 1861 he conceived the idea of conveying railway trains across the Straits of Dover, and designed a vessel

for that purpose, which he exhibited to the Admiralty; and in 1867 he designed a plan for shipping and unshipping the trains. He became a Member of the Institution in 1863. His death took place on 2nd February 1876 at his residence in Manchester, in the 66th year of his age, after a short illness, from chronic bronchitis aggravated by heart disease.

ROBERT NAPIER was born on 18th June 1791 at Dumbarton, his father being a blacksmith of that town, to whom he was apprenticed in 1807 for five years, after which he worked as a blacksmith and mechanic in Edinburgh and Glasgow. In 1815 he started on his own account in a small blacksmith's shop in the Gallowgate, Glasgow; and in 1821 he engaged in ironfounding and engineering at Camlachie, at the east end of Glasgow, where in the same year he built his first engine, of 12 H.P., for a flax-spinning mill in Dundee. In 1823 he built his first marine engine for the "Leven" steamboat, to ply between Glasgow and Dumbarton. In 1828 he removed to larger and more convenient premises, the Vulcan Foundry in Washington Street, adjoining the harbour of Glasgow; to which in 1835 he added the Lancefield Engine Works, and in 1841 a shipbuilding yard at Govan, a mile below Glasgow. Here many first-class steamers of all sizes have been built by himself and the subsequent firm of Robert Napier and Sons, for the merchant service and for the navies of various countries, employing at times more than three thousand workpeople. About 370 vessels were either engined or built, or both engined and built, by himself and his firm. He was early connected with steam navigation, being associated in 1830 with the City of Glasgow Steam Packet Company, most of whose vessels running between Glasgow and Liverpool were engined by him. In 1839 he joined in the establishment of the Cunard line of mail steamers to ply between this country and North America with the mails, the great success of which was largely due to the sound advice given by Mr. Napier, and to the high character of the vessels built by him. The first steamers for the Cunard line were commenced of 900 tons and 300 H.P.; but by his advice a larger size was

substituted, and he made the first four of these steamers 1200 tons and 400 H.P., a size which was subsequently more than doubled. He also built in 1856 the "Erebus," the first of the armour-clad vessels ordered for the British navy; and subsequently twelve more armour-clads for this and other countries. He became a Member of the Institution in 1856, and was President for the years 1863, 1864, and 1865; he received the members at his residence at West Shandon, on the Gareloch, on the occasion of the Glasgow Meeting in 1864. His death took place at West Shandon on 23rd June 1876 at the age of 85.

JOHN HENRY NYE was born on 15th August 1830 at Athis-Mons (France), and at the age of 16 entered the drawing office at the engineering works of Messrs. Varrall Elwell and Middleton, Paris, where he gradually worked his way up to the position of engineer to the firm, and would have become a partner had he lived. His death took place on 14th October 1876 at the age of 46. He became a Member of the Institution in 1870.

JOSEPH PHILIP RONAYNE, M.P., was born about 1820 in Cork, his father being the owner of large glassworks there. After learning surveying under Mr. O'Neill, he entered the office of Sir John McNeil and was engaged under him on some of the main Irish railways then in course of construction, and afterwards under Mr. C. Nixon in the construction of one half of the Cork and Bandon Railway. In 1854 he prepared a scheme for the supply of the city of Cork with water by gravitation; and from then to 1859 he was in California, superintending the construction of reservoirs, canals, and aqueducts, which were executed from his designs for bringing down to the gold fields the waters of the Sierra Nevada. Returning to Ireland he became a contractor, and executed the Queenstown branch of the Cork and Youghal Railway, and also laid out and executed the Cork and Macroom Railway; and commenced the construction of the Irish Southern Railway from Clonmel to Thurles, at present in course of execution. In 1872 he was elected Member of Parliament for his native city Cork, which he continued to represent till his

death on 5th May 1876. He became a Member of the Institution in 1853.

Charles Dyke Taylor, son of Richard Taylor, F.G.S., London, was born at Penmear, Cornwall, on 19th September 1845; and after completing his education as a civil engineer was employed as assistant to his elder brother in the management of the Val Sassam mines in the canton of Grisons, Switzerland, and subsequently in the same capacity at the Gonnesa mines in Sardinia. Returning to England in 1868 he was appointed resident manager of the Redruth and Chacewater Railway in Cornwall, residing at Devoran, the shipping terminus of the line. At the same time he was the representative in Cornwall and Devon of his father's firm, Messrs. John Taylor and Sons, being specially charged with the management of Wheal Friendship Copper Mine near Tavistock, of the Restormel Iron Mine near Lostwithiel, and of the Restronguet Tin Stream Works, Devoran, and the adjacent lead-smelting works; he also assisted in the management of West Wheal Tolgus Copper Mine near Redruth. In the Restormel Iron Mine and also in the submarine tin stream workings at Restronguet he adopted the system practised in collieries, but never previously introduced into Cornwall, of hauling to the surface in cages and guides the tram wagons used in the levels of the mine. Of the Restronguet Tin Stream Works he gave a description to the Institution in 1873 (see Proceedings 1873 page 155) on occasion of the Cornwall meeting; and in the visit then made by the members to Restronguet the very successful working was witnessed of two machines first introduced by him into Cornwall for dressing tin and copper ores, namely Collom's jigger and the propeller-knife buddle. In 1875 in consequence of symptoms of pulmonary disease he went for the benefit of his health to the Cape of Good Hope, and resided at Ookiep, the principal mine of the Cape Copper Company; but he returned in 1876 without improvement in health, and died at Falmouth on 24th September 1876 at the age of 31. He became a Member of the Institution in 1873.

Falkland Samuel Thornton was born in Birmingham on 16th February 1840, and on completing his education and taking an M.A. degree at Cambridge he joined the firm of Messrs. James Thornton and Sons, merchants. He took a very active part in the success of the Birmingham Volunteers, being captain of No. 6 company. His death took place on 22nd May 1876 in the 36th year of his age, from the results of an accident. He became an Associate of the Institution in 1864.

Edward Tomkins was born in Manchester on 17th September 1845, and after serving an apprenticeship in the works and drawing office of Messrs. W. Collier and Co., Manchester, was engaged in several works connected with railway plant and machine tools, in and near Manchester. In 1866 he retired partially from practical work, and resumed the theoretical study of civil and mechanical engineering; and in 1869 he was awarded a Whitworth exhibition, and in the following year a Whitworth scholarship. From 1866 to 1874 he lectured in Manchester and surrounding towns on subjects connected with engineering; and in 1872 was appointed lecturer on civil and mechanical engineering at Queen's College, Liverpool; but in 1873 failing health compelled him to abandon his profession almost entirely. In that year he published an elementary work on machine construction and drawing; and was engaged upon a more advanced work on the same subjects up to the time of his death, which took place at Buxton on 16th July 1876 in the 31st year of his age. He became a Member of the Institution in 1873.

Arthur John Whalley was born on 16th December 1832 at Kington, Herefordshire; and about 1852, after spending a few years in Australia, he returned to England and studied engineering in London under Mr. Hyde. He then went out to India, having obtained an appointment in Calcutta, and was engaged two years as an assistant engineer on the works of the East Indian Railway. He was afterwards employed about two years at Sydney and Melbourne, on the surveys of the Maitland and Morpeth Railway, and the

Muswellbrook Cassilis and Mudjee Railway; and then for two years in Mauritius under Mr. Longridge in the construction of the Mauritius Railways. He was next engaged for about two years in works on the Zuyderzee, Amsterdam, and afterwards in Monte Video, South America, for about two years. Returning to England about 1868 he undertook the superintendence of the iron mines near Truro belonging to the Agra Bank. His death took place in London on 18th January 1876 in the 44th year of his age. He became a Member of the Institution in 1874.

The Annual Report of the Council having been read and adopted by the Meeting, the President announced that the Ballot Lists had been duly opened, and the following Officers and Members of Council were found to be elected for the ensuing year:—

PRESIDENT.

THOMAS HAWKSLEY, ...	London.

VICE-PRESIDENTS.

I. LOWTHIAN BELL, M.P., F.R.S.,	Middlesbrough.
E. HAMER CARBUTT, ...	Burley.
WILLIAM MENELAUS, ...	Dowlais.
CHARLES P. STEWART, ...	London.
FRANCIS W. WEBB, ...	Crewe.
PERCY G. B. WESTMACOTT, . . .	Newcastle-on-Tyne.

COUNCIL.

CHARLES COCHRANE, ...	Stourbridge.
EDWARD A. COWPER, ...	London.
EDWARD EASTON, ...	London.
THOMAS R. HETHERINGTON, . . .	Manchester.
JOHN PENN, JUN., ...	Greenwich.
WILLIAM RICHARDSON, ...	Oldham.
JOHN ROBINSON, ...	Manchester.

PAST-PRESIDENTS.

Ex-officio permanent Members of Council.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . . .	Newcastle-on-Tyne.
FREDERICK J. BRAMWELL, F.R.S., .	London.
JAMES KENNEDY, ...	Liverpool.
JOHN PENN, F.R.S., ...	London.
JOHN RAMSBOTTOM, ...	Manchester.
C. WILLIAM SIEMENS, D.C.L., F.R.S.,	London.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., . . .	Manchester.

COUNCIL.

Members of Council remaining in office.

DANIEL ADAMSON, ...	Manchester.
JOHN ANDERSON, LL.D., F.R.S.E., .	London.
JOSEPH ARMSTRONG, ...	Swindon.
HENRY BESSEMER, ...	London.
JEREMIAH HEAD, ...	Middlesbrough.
FREDERICK W. KITSON, ...	Leeds.
HENRY H. LAIRD, ...	Birkenhead.
WALTER MAY, ...	Birmingham.

The following New Members were also declared to be duly elected:—

MEMBERS.

JAMES HART, ...	Manchester.
HENRY KIRK, ...	Workington.
HECTOR MACCOLL, ...	Glasgow.
IRVING M. SCOTT, ...	San Francisco.
ALFRED ALLEN STOKES, ...	Bengal.
MAXIMILIAN RICHARD WESTERN, . .	London.
ROBERT WILKINSON, ...	Lima.

Mr. C. COCHRANE proposed the following motion, in conformity with the resolution of the Council at the last meeting of the Institution:—"That the business and house of the Institution be removed to London." He reserved until the end of the discussion any observations that he might have to make on the subject as an individual member.

Mr. E. H. CARBUTT seconded the motion, and remarked that this question had occupied the attention of the members now for some years; and their opinions having been asked by circular by some who had taken an active interest in the matter, the result of the application had been that out of the 834 members applied to (omitting only the Council and distant foreign members), it had

been found there were 558 members in favour of removing to London, while only 22 unfavourable answers had been received, the rest therefore being either doubtful or perhaps in favour of Birmingham or not caring to express an opinion. He had enquired the attendance of the Birmingham members at the several meetings of the Institution for the past three years, during which this question had been under consideration; and found that, commencing with the meeting there in January 1873, which was attended by 60 members, of whom 27 belonged to the Birmingham district, the highest number attending any meeting in Birmingham had been 34 members from Birmingham and the neighbouring district, the total number of members in that district being about one hundred. With reference to the attendance of Birmingham members at the other meetings, there had now been several meetings in London and Manchester, and at the London meeting in May 1873 there were 125 members, of whom only 7 belonged to Birmingham; at the summer meeting in Manchester in 1875 there were 227 members, of whom only 26 belonged to Birmingham; at the London meeting in May last there were 87 members, only 8 belonging to Birmingham; and at the Manchester meeting in October last there were 69 members, of whom only 6 were from Birmingham.

It had been urged by several of the members in the Birmingham district that the head-quarters of the Institution should be kept there because it originated there thirty years ago, when there was a total of only sixty members; but at the time of its origin the railway facilities for getting to Birmingham had been relatively the greatest, and it had been thought that as there were a good many engineers in that locality the professional status might be kept up. It was also said that Birmingham and the district had at the present time a larger number of resident members than any other provincial town; this however he found to be a mistake, unless perhaps the whole of Staffordshire were included; for while London had more members than any other district, the district of Manchester, with Liverpool, Bolton, and other towns which regarded Manchester as their centre, included as many members as the Birmingham district.

A further argument was that a removal was undesirable on the ground of the danger of uprooting the tree from the soil where it had grown; but he did not think this could carry any weight with it. If the Institution could not exist when it was removed from Birmingham, the fault must be in the Institution; if it had shown more spirit and fulfilled its duties more completely, he thought there never would have been the Iron and Steel Institute, which had only been in existence a few years, and numbered already nearly as many members as their own Institution. He believed if they had taken a broader basis, and admitted other members, and had livelier discussions, the Institution would have occupied an advanced position; and had it been moved to London, its importance would have been greatly increased.

A circumstance bearing upon this question, that had just come under the notice of the Council, was that among the British commissioners appointed for the next Paris Exhibition there was not one representing the Institution of Mechanical Engineers; and the probable reason appeared to be that the Institution did not appear in the London directory, and that if it had been located in London the members would have been represented at the Exhibition by the President; and it was known that mechanical industry was by far the most important industry represented on those occasions. He might also mention that one of the members, of high standing in the profession, had intimated his intention of resigning, because he could not get to meetings at Birmingham, but could readily attend in London though living many miles out. In consequence of the present railway facilities it was much easier to come from almost any provincial centre to London than it was to come to Birmingham; and even in his own district of Leeds, where there were a great many members, although they could now perhaps come to Birmingham in the same time as to London, there was not so great a choice of trains as to London.

Mr. W. A. Adams said that, as one of the oldest members of the Institution, he had a great interest in its success, and his feeling was that it was not a judicious thing to remove it to

London. He considered it should be a country institution, not a London one; it was not important whether it was in Birmingham or in any other large town, so long as it was free from London. For any scientific institution, taking it from the commencement, London was undoubtedly the best seat; but this Institution was now an established fact in the provinces, much respected throughout the mechanical world and holding a high position. When this Institution was first formed, the Institution of Civil Engineers confined itself pretty much to civil engineering subjects, the papers being connected principally with public works and railways; but afterwards, probably from these works becoming slacker, there were fewer strictly civil engineering papers, and mechanical papers were received and still continued to be received. He had heard it remarked that members of this Institution read papers before the Institution of Civil Engineers; and a paper of his own had been referred to as an example. But that paper had been, not on the manufacture of rolling stock, but on the general question of the dead weight of rolling stock, which was not purely a mechanical question; had the paper been on the mechanical construction of rolling stock, he should have brought it to this Institution.

With regard to the Iron and Steel Institute, its success was due to its having a speciality so large that it could not be interfered with in any way by the Institution of Civil Engineers. The success of the Institution of Mechanical Engineers was attributable he thought to its provincial meetings, which were held in various places, and were always largely attended. If the Institution were removed to London he thought it would compete with the Institution of Civil Engineers, the two would be side by side, doing practically the same work and having the same kind of papers, and the larger institution would naturally take the lead; if that were so, this Institution would not have the prestige which it now had when its meetings were held in the provinces. It would therefore be best he thought to let well alone, and to let the Institution remain in the provinces, as it was; at the same time he had no desire that it should remain in Birmingham; the seat of the Institution should be where it would have the largest success, be that where it might.

Mr. P. D. Bennett considered the Institution was essentially a national provincial institution, and as such it should be maintained. If it were taken to London he concurred in the opinion that it would be placed in competition with the Institution of Civil Engineers, whose charter stated that it was formed for the general advancement of mechanical science, but more particularly for promoting the acquisition of that species of knowledge which constituted the profession of a civil engineer. That Institution however covered all the ground which the Institution of Mechanical Engineers had power to discuss at the present time; and therefore in going to London this Institution would at once have to take a second place, and would be deprived of that independence and individuality which it at present enjoyed. The removal of the Institution he considered would change its character, and deprive it of that basis which its founders had had in view in establishing it as an essentially national provincial institution. The seat of the Institution was altogether accidental; but as Birmingham was the place where it had grown, and had taken deep root and prospered, and had attained a success of which all were proud, he thought that to remove the Institution to London would be to risk the influence and success which it at present enjoyed in the provinces. He did not know what the Institution had failed to do in its present position; it began with sixty members and there were now upwards of a thousand, all of whom had joined it as a national provincial institution; and if it were removed to London it would become at once a London institution, be governed by London men, and the organisation which the founders so wisely established would be essentially changed. There was he thought a great principle involved in the question, and the provinces should rouse themselves to a sense of the disadvantages under which they laboured by London absorbing every institution when it had attained to anything like usefulness and dignity; he did not see why London should absorb all the best talent and the best advantages which the provinces had created. Removal to London he thought would damage the prestige of the Institution, and he did not know of anything which the Institution was not capable of doing better in

the provinces than in London. If any Birmingham members had shown a want of appreciation of the advantages which the Institution had given, that was not the fault of the organisation of the Institution, but of the members themselves; and it did not touch the principle that the Institution was essentially a national provincial institution, and ought to be so regarded.

As to the opinion of the members having been ascertained by the memorial which had been signed respecting this question, he did not consider that the 558 members who had signed the memorial could be counted as having voted for the removal of the Institution; their opinion had simply been asked as to whether the question should, or should not, be considered by the Council; and the answer given in signing the memorial was to that question only. There were many members he believed who would vote for the matter being remitted to the Council, who would not vote for the absolute removal of the Institution; and it seemed to him therefore that those who signed could not be taken as all supporting the proposal to remove to London.

With regard to the number of Birmingham members attending meetings in Birmingham and the number attending in London and elsewhere, he thought a comparison could not be correctly made between the attendance at the meetings in Birmingham, at which only the ordinary reading of papers took place, and the attendance at the meetings in London and elsewhere, at which there were attractions that the Birmingham meetings did not present, in the shape of visits to engineering establishments and other works. With regard to the remark that if the Institution had discharged its duty the Iron and Steel Institute would not have been established, it was not a matter that depended upon the Birmingham members of the Institution, but rested with the Council. The Institution had been managed very economically, with a view to extending its usefulness in the provinces; and the result was the present credit balance of £12,000, which he hoped would be a nucleus for the extended usefulness of which he was sure the Institution was capable. The very object he considered of its being established in the provinces had been to keep it entirely distinct from the

Institution of Civil Engineers, which covered all the ground that this Institution could occupy; and if the Institution were removed to London it would at all events be subordinate to the other, and would in no way hold the independent and honourable position it at present occupied. He considered it important therefore to adhere to the principle that this was a national provincial institution, without reference to its particular seat.

Mr. R. PRICE WILLIAMS observed that many members of this Institution were also members of the Institution of Civil Engineers; and the cordial manner in which the mechanical engineers had been received by that Institution on the occasion of the London meetings showed there was no idea of competition. As a member himself of both Institutions he felt assured there was plenty of room for both in London. Only recently, in asking other members of the Institution of Civil Engineers whether they were going to attend the present meeting, he had received the reply that they were not members of this Institution, but if it were removed to London they would gladly become so. It was really not a national provincial, but a national institution; and therefore he considered its proper home was London, as everything national gravitated to London. Of the present total number of members at least one fifth he believed were London members, while the number in the Birmingham district would amount to only about half as many, and this was an important consideration for the members. He hoped it would now be decided to remove the Institution to London, feeling confident that the removal there would be beneficial to its interests.

Mr. F. J. BRAMWELL said he was at a loss to see what it was hoped would be gained by removing the seat of government of the Institution, because that removal of the seat of government was really all that the proposed change would lead to. The members now held one meeting in the year in Birmingham, one in London, one in Manchester, and the Summer meeting in some town to be selected; therefore all that remained to Birmingham at present was one meeting and the offices of the Institution. It was now proposed

to remove these offices to London, and thereby to become a London institution; but was any proposal contemplated of change in the meetings? He thought that any change would be a mistake in the place of meetings as now settled; the present Summer meetings in particular were a great success, and if it were endeavoured to make any such change as holding weekly or fortnightly meetings in London, the result would be injurious competition with the Institution of Civil Engineers. There was a mistaken notion that the designation of Civil Engineer had a meaning in contradistinction to that of mechanical engineer; it had no such meaning, but was simply in contradistinction to military engineering; and the charter of the Institution of Civil Engineers stated that the object of that Institution was the promotion of mechanical science. The statement that some time ago the Institution of Civil Engineers did not accept mechanical subjects, but that now under a pressure of want of papers they did so, he thought was a mistake; as an old member of that Institution he believed they had always accepted mechanical subjects, when those had been of sufficient importance; and as a member of the Council he could say that they were most desirous to get good mechanical papers. The Civil Engineers received this Institution as a country institution on the occasion of the London meeting in the spring of each year, and gave the use of their rooms, with every possible facility; but that could not be expected when this Institution was settled in London, having its seat of business there and becoming a London institution. No doubt other places of meeting would be available; but the fact of calling this a London institution and having its seat of business there would prevent its acceptance of the hospitality of the Institution of Civil Engineers, which could no longer be offered, because it would not be reasonable that they should offer encouragement to an institution which was there in competition, for that was really what it must come to. Of those who were members of both institutions there were many he doubted not who would prefer the older, if it came to a choice between the two, as he feared would be the case if the name of a country institution were taken away. It would be very undesirable he thought that country institutions of importance should no longer

exist; but unless it were determined that this should be the case as regards all large provincial institutions, he could not see what ground there was for removing this particular Institution. Moreover, although the rules of the Institution had not definitely fixed the locality of its seat in Birmingham, this was in his opinion distinctly understood and was fixed by practice during a quarter of a century, before the present question was thought of; and every member who had joined the Institution had joined it well knowing where the seat of government was.

Mr. T. W. Plum said that, although it was more convenient for himself (though not exactly a Birmingham member) to attend meetings in Birmingham rather than in London, he could not leave out of view the convenience of a very large number of members who lived in various parts of the country and who could not possibly attend meetings in Birmingham so conveniently; but in his opinion the objection to the continuance of the Institution in Birmingham had been to a large extent removed by holding meetings alternately in London, Manchester, and other places. There could not however be much objection he thought to the offices of the Institution remaining in Birmingham, as the locality of the offices was a matter of minor importance; but if it was contemplated to lay out a large sum of money in building, as at one time intended, he should much prefer to see the funds applied to something else, because to build a large room for one institution to meet in once in three months was in his opinion a waste of money. A proposal had been made some time ago to have one large establishment in London, capable of accommodating all the institutions in their turn, which he should like to see accomplished.

Mr. W. W. Hulse believed that in the proposal to remove the Institution to London there was not any intention or desire to depart from the present practice of holding meetings in the provinces. The point was that with the removal any desirable modification of the rules and government became possible, but while the Institution remained in Birmingham and under the existing

rules the government was personal, and no change or modification could be effected except by personal voting at the anniversary meetings held there. The local members were always present at such meetings, and naturally if a proposed change were thought to be adverse to them, there would be a full attendance to oppose it. This would be the case if the Institution were placed in any other provincial locality; but if in London, there would be less difficulty in securing the attendance of members from all parts of the country to counteract undue local influences. The discussion of this question of removal began some ten years ago; but five years ago the non-removal had been carried so far that at the Liverpool meeting the idea of building a house in Birmingham for the Institution was announced by the President for the consideration of the members, and he had understood from Mr. Robinson that plans had been got out for a new building and contracts were in hand. As regarded the subjects of papers suitable to be read before the Institution, a mechanical paper that was national in its scope might be read before the Institution of Civil Engineers, because that was a national institution, and it was national because it was in London. If a paper on a national subject was read in a provincial town, the prestige connected with it was not so great as if it was read in London; and that was the reason why London was preferred even in the case of subjects which were undoubtedly more suitable for this Institution than for the Institution of Civil Engineers. There need be no fear he felt sure of any conflict in this matter with that Institution; there could be no doubt that there was room enough for both and that their lines were sufficiently distinct. Nor would the removal to London interfere with any of the branch or provincial associations, inasmuch as this Institution had not interfered with those in other provincial towns, such as the one at Middlesbrough in which Mr. Head had taken so active a part. Every locality had its own specialities, and a paper on cotton-spinning machinery might be out of place in London or in Birmingham, just as one on pin-making might be unsuitable out of Birmingham; there was no reason why every large provincial town should not have its own local institution, and thereby strengthen

the national institutions. It appeared to him a startling fact that, while mechanical engineering would play a more prominent part than anything else in next year's Paris Exhibition, this Institution was not represented there; if the Institution had hailed from London, it would have been recognised.

Mr. J. Robinson said there was a mistake in the reference that had been made to building a new house for the Institution in Birmingham; the Council looked out for a site some years ago in order that the present house might be replaced by one suitable for such a largely increasing Institution, but he did not know of any plans or contract for building. He thought perhaps the first reason why Birmingham had been selected as the head-quarters of the Institution at the time of its foundation had been simply one of locality, as the most convenient place of meeting for the various mechanical engineers of the country. It was true there were now greater facilities than at that time for getting to London as compared with Birmingham; but it was equally true that a large number of the members resided north of the Birmingham district. On this account he had proposed the Autumn meeting each year in Manchester, which had been adopted, with the object of giving the members who lived in the northern districts a regular opportunity of attending a meeting of the Institution within convenient reach of their places of business. It might be easy enough for the heads of large establishments, having frequent engagements in London, to go there to attend meetings of the Institution; but there were many of the younger members who had not those opportunities, and whose interests ought not to be neglected. Assuming that a removal to London would not affect the present very convenient arrangements as to the places for holding the Institution meetings in four different districts during the year, there was a further consideration with regard to the seat of government, namely that for the members of the Council generally Birmingham was as convenient a place of meeting as London would be. Another point not yet touched upon was that removal to London would necessitate paying London prices for the offices of the Institution and for the persons

employed; and even in the case of an amalgamation of several institutions he believed the rent of buildings alone would amount to more than all the expenses now incurred in the administration of the Institution in its present locality. For the sake of the northern members he would rather come to Birmingham, and pay a smaller rent than the removal to London would necessitate.

Mr. R. C. Rapier observed, as to what would be gained by going to London, that the best of everything went there, and he did not see why the Institution should be any exception to that rule. If removed to London it would have a career before it which might truly be called European; it would have a European position, which it must be admitted it did not appear now to have, from what had been mentioned with reference to the Paris Exhibition. In reference to the convenience of Birmingham as a centre for members coming from all parts of the provinces, he himself came from Suffolk, where there were many engineers; and for that district, as also for North Lancashire, Cumberland, Northumberland, and the whole of Yorkshire, he ventured to say that London would be the most convenient place of meeting, and the attendance at the meetings would be increased if they were held there. If the Institution were removed to London, he apprehended the number of meetings held would be not merely four in the year, but more likely twenty; and so far from its coming into direct competition with the Institution of Civil Engineers, he considered neither institution had anything to fear from healthy competition, if that were likely to result; there was plenty of room for this Institution in London, without interfering with any of the other societies already established there. The Institution had now attained an importance, as regarded both its number of members and its income, with which he thought four meetings in the year were entirely incommensurate. The question of building better premises, and making a better outward and visible show—which after all was of great importance—had he thought been most opportunely touched upon as part of the discussion respecting the removal or non-removal of the Institution, because it would have been a great misfortune to have spent the present

capital upon a building in Birmingham, and then to find that it was a mistake. In going to London, there would however be no occasion to build rashly, and that question might with advantage be let alone for some time; with all the large places of meeting that were to be had in London there would be no difficulty whatever, and the increased cost of offices &c. that had been referred to would be more than met by the present surplus income, amounting for the past year, as seen by the report of the Council, to several hundred pounds. For increasing the number of meetings, and improving the character of the discussions, he considered the most advisable course was to remove to London at once, and the arguments on the question appeared to him to be wholly in favour of London.

Mr. JEREMIAH HEAD mentioned that, in the case of the Iron and Steel Institute, whose head-quarters had some years ago been removed to London, which was now the seat of government where all the routine business was carried on, he had ascertained that the expense so far as the offices were concerned, exclusive of the hire of large rooms for the meetings, was under £100 a year. It seemed to him that the question of removal resolved itself into one of the greatest convenience for the greatest number. Coming himself from the Cleveland district, where there were a very large number of engineers, he strongly sympathised with the movement for going to London; and having had a good deal of conversation with many other engineers in that district, he found them almost unanimous in preferring to go to London to the meetings rather than to Birmingham. The convenience of the members of the Council themselves he thought should not influence the decision much; but as it had been referred to, he might say that he, for one, could certainly get to London at any time an hour sooner than he could get to Birmingham. Competition with other societies had been spoken of as a probable evil; but he ventured to think it would be a probable good, for he was sure the Council and officers of the Institution could not meet in London, where there were so many active societies, so well organised and so well managed, without feeling that stimulus which he thought was needed to make this

Institution keep pace with the times. Moreover the success of the Institution was dependent not only on the attendance of members, but also on keeping up its interest by getting good papers; but no one would take the great amount of trouble which was necessary to prepare a really good paper for an Institution like this without some motive; and he thought it might be considered a fair and legitimate motive, that any one having a mechanical invention should wish to have some means of making it known, and with that object should bring it before an Institution such as this. Now the London press was the national press, and institutions which met in London excited he thought a greater amount of interest amongst the London press than those which merely ranked as provincial institutions; he believed therefore that members who wished to make known important inventions would be more induced to communicate papers by the Institution being in London.

Mr. E. A. COWPER said that, as the only one now left in the Institution of the five members who originated it, he might mention that at the first meeting, at which they had succeeded in getting together as many as sixty, he had seconded the resolution proposed by Mr. George Stephenson, that the Institution should be formed; and he could state definitely that the Institution was not started essentially as a provincial institution; there was no accidental omission of a declaration that it was a Birmingham institution; it was not intended that it should be a Birmingham institution, but the object with which it was started was to represent the mechanical engineering of this country. It was considered that, as the railways then came to Birmingham as a centre, that would be a convenient place to meet in; but when the Trent Valley line came to be made, Birmingham was no longer in the direct line to Manchester and the North. The feeling of the members appeared to him to be that London was now much more convenient for them to go to; at all events it was the place to which they wished to go—whether for business or for pleasure or for both combined—rather than to Birmingham. That seemed to him a very strong reason, and did away with any objection as to the inconvenience to members north

of Birmingham, in consequence of removing the Institution further south. It had been hoped, when the Institution was formed, that it would be taken up warmly by the ironmasters of the neighbouring district, and every effort had been made to interest them in the Institution; but although even the day of meeting had been changed to make it more convenient for the ironmasters, the Institution did not at first get their support to help it forward; since however it had become a successful institution, many of them had joined. The Institution was very much respected in the neighbourhood, and it was much respected elsewhere; and a question frequently asked was, why did it not come to London. The metropolis he considered was the proper place for an institution representing the mechanical engineering of the country. He should be very sorry if the removal to London should cause inconvenience to members in Birmingham; but he was in hopes that all the members in Birmingham, seeing how for thirty years the London members had come there, would now consent to come to London. There might be a few who would not find it convenient to do so; but as there were far more members in London, he thought the convenience of the larger number should be taken into consideration. The convenience of members however was a less important consideration than the question of what was best for the Institution, and how could it best perform the duties devolving on it. If by going to London, where the Institution would be well represented, a large increase of members should be obtained, including the best mechanical engineers from all parts of the country, the removal would certainly be doing the greatest possible good to the Institution.

Mr. C. W. Siemens remarked that the agitation of the present question began at the time when he had the honour of being the President of the Institution. At that period the question of erecting a suitable building in Birmingham had been under consideration for some time, because it was felt that they ought not to occupy a house which was neither good for an office nor useful for a dwelling for the secretary nor for holding the meetings;

and it was thought that the Institution, as a provincial institution with head-quarters at Birmingham, should have a proper house there. In order to get the requisite information for considering the question, enquiry was made by the Council as to the probable cost of such a building, and where would be a possible site for it; but this was only a private enquiry and no expense was incurred, and no action was intended to be taken until after consulting the members. When the question was brought before the members by himself at the Liverpool meeting, in order that it might be properly discussed and considered by them, it soon became evident that a number of them objected to carrying out the plan proposed; and it was then his duty as President to act with perfect impartiality. It had never occurred to him before that the Institution ought to remove to London, nor had he any fixed idea that it should remain where it was; and the Council resolved to have the matter fairly and properly discussed and tried, and to avoid taking any hasty action. They had accordingly tried step by step whether such a move would be to the interests of the Institution; and he had willingly concurred in the proposal to have one meeting and afterwards a second meeting in London, so as to test by the number of attendances and by the facility of getting good papers whether the Institution could flourish in London, or whether it might be considered exclusively a provincial institution. The result of these experiments had been so far satisfactory that the Institution had decided to hold all its meetings but one out of Birmingham; and the question now really before the members was only whether the government ought to be in Birmingham or ought to be removed to London. This appeared a very simple question; but it meant the house of the secretary and also a place where the Council meetings and the important general meetings were to be held, and in that respect it was a serious question. The frequent Council meetings he thought it would be better to hold in London, notwithstanding what had been said about the greater expense; they were generally composed of those members who could be reached without much trouble; and though personally he might feel that the London members of Council

would be thus called upon more frequently to attend meetings, yet in the interest of the Institution he thought it would be better that those meetings should be held in a great centre like London. He thought there would be an advantage also in obtaining good papers, if the Institution were located there; London being one of the centres of the business world, there were great facilities for meeting with those who were likely to give good papers. He should be much opposed to any proposal by which the meetings in London should be very much multiplied; the Institution should remain a national Institution of the Mechanical Engineers of all England, and as such should hold its meetings in the different centres of mechanical industry. But if the question were reduced to one of mere government, he thought the facilities for carrying out the government of the Institution would be carried out more efficiently in London than in Birmingham. After having stood upon neutral ground for the last five years, he was now ready therefore to give his vote in favour of the removal to London.

The President then put the motion to the meeting, and declared it to be undoubtedly carried.

Mr. A. Paget then moved an alteration in the rules for the purpose of carrying into effect the resolution for removing the Institution to London.

The President remarked that such a motion for alteration of the rules was not in order, as notice had not been given of it; but it might be taken for granted that the rules were so far altered as to authorise the Council to take all necessary and proper steps for carrying out the resolution that had just been passed.

Mr. A. Paget said that on this understanding he moved that it be left to the Council to carry out the details of the resolution that had just been passed; the motion was seconded by Mr. R. P. Williams, and was passed.

Mr. A. PAGET then moved a resolution, according to notice, to enable the Council to increase the number of meetings, if they found it advisable to hold additional meetings, in the evening or otherwise, in consequence of increase in the supply of papers from the removal to London. He moved accordingly that Section V, part 1, of the Rules be altered to—"There are to be at least four general "meetings in each year, at least three to be held in London or "elsewhere, on such dates as the Council shall deem convenient, "and one to be an Annual Meeting held in the summer in different "localities to be arranged by the Council; a Meeting in London in "January to be the Anniversary Meeting for the annual election of "officers." Also that Bye-Law I be altered to—"The General "Meetings to be conducted as far as practicable in the following "order."

The motion was seconded by Mr. E. J. C. Welch, and was passed.

Mr. A. PAGET said that the next alteration was with a view of clearing the decks for action in London. According to the present rules the meetings were to be held at four o'clock; but that hour was not always convenient, and the meetings were not really always held at that hour, and he wished to make the rules accord with the practice. He therefore moved that Bye-Law I, part 1, be altered to—"The chair to be taken at such hour as "the Council may direct from time to time."

The motion was seconded by Mr. C. D. Fox, and was passed.

Mr. A. PAGET said the next alteration referred to a bye-law as to introducing friends, with reference to which there had been considerable difficulty at some of the meetings; and he therefore moved that Bye-Law II be altered to—"Each member to have "the privilege of introducing one friend to any of the meetings, "except during such portion of any meeting as may be devoted to "any business connected with the management of the Institution, "when visitors shall be requested by the Chairman to withdraw, if "any member wishes this to be done."

Mr. F. W. Webb suggested that the number be not limited to one friend, in order to provide for the author of a paper being able to introduce several friends, according to the practice of the Institution of Civil Engineers.

Mr. C. W. Siemens remarked that it was provided for in that case by several tickets for friends being sent to the author of each paper, in addition to the ordinary admission of one friend by each member.

Mr. J. Tomlinson seconded the motion, and had no doubt the Council would readily grant the same privilege to the author of a paper as the Institution of Civil Engineers. The motion was passed.

Mr. A. Paget moved that Bye-Law I, part 4, be altered to—"Communications approved by the Council to be read by the "Secretary, or by the writer of the paper if he prefers to do so." He thought it would be agreed that a member who had written a paper was sometimes able to read it better than anyone else could.

The President said the Council considered that it would be an improvement if the motion were put in this slightly altered form:—"Communications approved by the Council to be read by the "Secretary, or, with the assent of the Council, by the writer of the "paper."

Mr. A. Paget adopted the alteration; and the altered motion was seconded by Mr. A. Marshall, and was passed.

Mr. A. Paget moved a resolution for changing the method of enabling the members to correct the reports of discussions in the proceedings, and remarked that hitherto there had been great difficulty in correcting the reports furnished by the secretary, in consequence of the length of time that had elapsed between a member speaking and the receipt of his condensed remarks. He therefore moved that—"After each meeting the Secretary shall "send as soon as possible to each member who has spoken during "the discussion a full report of the discussion, accompanied by a "copy of what the secretary proposes to insert in the proceedings,

"as the condensation of the speaker's remarks. If not returned by "the member within a week, the secretary may consider his "condensation accepted by such member as correct."

Mr. C. D. Fox seconded the motion, and remarked that the alteration would accord with the practice of the Institution of Civil Engineers, which he thought had worked admirably.

Mr. L. E. Fletcher considered a week would be too short a time to fix for the return of the proof, because a member might be travelling abroad at the time.

Mr. C. W. Siemens remarked that no doubt occasional complaints of the reports of speeches might arise, and could hardly be avoided, but he thought the proceedings were remarkable for the perfect manner in which the discussions were reported, and it would not be advantageous for the method of correcting to be fixed in the way proposed by the resolution. He suggested that this had better be withdrawn, and that the Council should consider what plan could be safely substituted with the view of ensuring the publication of the proceedings as soon as possible after the meetings, consistently with a perfect rendering and with good sense, so that the mistakes might not be fallen into of some other institutions in which the discussions were printed he thought without sufficient care.

Mr. F. W. Webb seconded the proposal.

The President said that if the matter were left in the hands of the Council they would carefully consider the suggestion. The motion was accordingly withdrawn.

Mr. A. Paget proposed a bye-law to change the practice with regard to making the large-scale drawings for the papers read at the meetings, and remarked that there was no doubt they had had great difficulty in getting good papers. Circulars had been issued by former Presidents urging the members to contribute papers, and he knew that contributors had experienced great difficulty in making good wall drawings; these were so totally different from ordinary mechanical drawings that there was much more trouble and expense in their preparation than if they were done by the Institution staff accustomed to that kind of work.

He therefore moved that—"When a paper has been accepted by "the Council, the writer of the paper shall furnish to the Secretary "sketches of the drawings required, in such shape and to such "scale as may be most convenient to the member; these shall be "enlarged and coloured in a suitable manner by the secretary at "the cost of the Institution."

Mr. H. Chapman seconded the motion.

Mr. J. Robinson agreed that, although the preparation of the drawings might be easy to some members who had large drawing offices, it would be an important assistance to others to have their drawings prepared for them by the Institution; but there would be a difficulty in carrying this out satisfactorily, unless sufficiently complete scale drawings were supplied by the members.

Mr. E. A. Cowper drew attention to the fact that it is the present practice for the drawings to be prepared by the Secretary when the writer of the paper was unable to do so, and a large amount of assistance was given by the Institution in this way to the writers of papers, the writers being responsible for the drawings illustrating their papers. The present proposal therefore only amounted to making a rule for that which was already a practice.

Mr. A. Paget said that was quite correct, but it was not generally known to the members, and he only wished it to be made known through the rules that a member giving a paper might if he wished have the assistance of the Institution in preparing the drawings for its illustration; and he would substitute scale-drawings for the sketches to be supplied by the member for this purpose.

The President remarked that there had not been any notice given of the terms of the resolution now proposed, and the Council had therefore not had an opportunity for considering it. He thought the subject could not be dealt with in so unlimited a way, and that some discretion must be exercised by the Council in reference to the preparation of drawings by the Institution, as there might be cases involving an excessive amount and cost of drawings that would not be right for the Institution to incur. He suggested therefore that, as the subject had been brought on so suddenly, it had better be left for the Council to take it into consideration.

Mr. F. J. BRAMWELL remarked that as the object of the proposed resolution was only to make known to the members the fact of assistance in preparing the drawings being rendered by the Institution, the object would be attained by notifying upon the list of "Subjects for Papers" that was annually issued by the Council, that anyone communicating a paper which is accepted may if he desires have the assistance of the staff of the Institution in preparing his diagrams, subject to the approval of the Council.

Mr. A. PAGET said he was quite satisfied with the suggestion, and the motion was accordingly withdrawn on the understanding that this suggestion was adopted.

The following paper was then communicated :—

ON HOMOGENEOUS IRON, AND THE DEGREE OF HOMOGENEITY TO BE EXPECTED IN IRON PRODUCED BY VARIOUS SYSTEMS OF PUDDLING AND SUBSEQUENT WORKING.

BY MR. HENRY KIRK, OF WORKINGTON.

Manufacturers of finished iron are frequently blamed by engineers for not giving them the exact qualities required, and they excuse themselves by saying that the pig iron supplied to them under the same name varies very much in its composition, and that they cannot make an invariable product from it. Smelters affect to regard complaints of the quality of pig iron as purely imaginary, but they themselves find fault with the minerals supplied to them, and mine owners are very ready to tell them that they can only give such materials as the mines yield. Thus every one exonerates himself, yet the truth is that no one of the departments is without its difficulties; and if each, instead of ignoring those of the others, would patiently examine them, and endeavour to remove, mitigate, or neutralise them, in the end all would be gainers. It is from such considerations that this paper is brought forward, in which it is the writer's intention to present some facts and offer some remarks from an ironmaker's point of view.

Words sometimes alter their signification so much in course of time that it is occasionally difficult, during the period of transition, to embrace all the shades of meaning current in any short definition; and if the title of this paper had been confined to "Homogeneous Iron," numerous precedents might have been found for a departure

from the strict original sense of the term "homogeneous." But it is contended that many such departures give rise to ambiguity and confusion, and to a loss of valuable time, which ought to be avoided. Thus the word "puddling" was originally restricted to the working of refined iron, which never became thoroughly liquid, but was in a "puddle" or pasty state throughout; and when unrefined pig began to be worked, and was found to melt thin and boil up freely from the rapid escape of carbon, the process was termed "boiling." But as the puddled iron was better than the boiled, there was the temptation to sink the word boiling altogether, and this has been done so completely, that now, when we want to speak of the old puddling process—which is still carried on at all the best Yorkshire works and at many others where the very highest quality of iron is made—it requires a lengthy description to convey the intended meaning.

The term homogeneous seems to have been first applied to iron about twenty years ago, and it meant a comparatively pure iron manufactured by melting, too low in carbon to be called steel, in fact presenting none of its characteristics. But within the last ten years makers of homogeneous iron have appropriated the term steel, steel being something better than iron; and now there appears in some quarters a disposition to adapt the word homogeneous to iron produced by puddling, whereas puddled iron is not, and perhaps cannot be made, truly homogeneous. It is highly probable that the use of the term steel has very much hindered the employment of true homogeneous iron in works of construction, for which it appears to be eminently fitted, by creating false impressions as to its hardness and the expense of working it, and it is a question whether the appropriation of the term homogeneous will help iron manufacturers nearly so much as the closest approximation to its most valuable properties which it is in their power to make. But here arises a difficulty: the finely crystalline appearance of such iron, when cut round with a chisel and broken suddenly off, finds little favour with engineers and consumers, while the fact of its being remarkably strong in its hot as well as in its cold state, and requiring a good deal of fire to heat and muscular force to work, excites

prejudice on the part of those who have to expend their labour upon it.

The writer will now endeavour to show, first, what homogeneous iron is, and what are its properties; next, how far the conditions of various modes of puddling are compatible with the production of similar iron; and lastly, how homogeneity is affected by the subsequent operations of hammering, rolling, heating, piling, &c.

Homogeneous iron will be considered here as iron of the same kind or nature throughout, and consisting of similar parts; thus iron may be homogeneous and yet contain all the elements usually associated with it, such as carbon, silicon, sulphur, phosphorus, and manganese: but iron containing cinder cannot be truly homogeneous, because the nature of cinder is altogether different from that of iron, and in fact cinder does not combine with it at all, but only remains diffused throughout the mass. Iron produced by melting and casting into solid ingots, carefully heated and well worked, may properly be called homogeneous. Such iron has no right to the term steel when the carbon is not above 0·30 per cent., which is an amount sometimes exceeded in the very best brands of wrought iron; for instance, an analysis of Swedish iron is given by Percy with 0·386 per cent. of carbon, and one of Russian with 0·34 per cent.

Homogeneous iron—or mild steel as it is now called—is remarkable, as compared with puddled iron, for its high degree of strength and ductility combined. This is well exemplified in the samples of mild steel and iron hoops of which tests are given in Table A. The pieces were about 6 ft. length each, and the testing machine was one specially constructed for ascertaining the tensile strain and ductility of telegraph wire. On the face of it, the steel appears twice as good as the iron, taking strength with ductility; but when it is considered that, to obtain the comparative value for work, say by Mallet's coefficient, half the breaking weight has to be multiplied by the elongation per foot, it will be seen that the steel has about 4 times the value of the iron. This however does not exhibit the whole of the difference between the two. By the same rule of calculation, No. 16, the lowest of the steel, gives nearly 12 times

as high a value as No. 4, the lowest of the iron; while the ratio of difference between the lowest and the highest steel is as 1 to 1·62, and the ratio of difference between the lowest and the highest iron is as 1 to 9·06, showing that the variation between the different samples is $5\frac{1}{2}$ times as much in the iron as in the homogeneous metal.

No doubt this is an extreme case, but it is selected as well adapted to show the full value of homogeneity, which would be perfect in the steel, from its having been worked down to so small a size, but more imperfect than usual in the iron, for reasons which will be given in the last division. As ingot iron—to use the term recommended by the International Committee at the Philadelphia Exhibition—is made larger in size, it is less and less uniform, because of internal crystallisation, accompanied often with air bubbles. On the other hand, as wrought iron is made larger in size, a greater degree of uniformity can be obtained, as is done in the manufacture of armour plates, by building up from numerous small pieces.

It is not the intention here to deal with plates nor with hammered iron, nor specially with angles or rails, because the experiments now first made public were conducted entirely upon rolled bars. As the manufacture of iron from ingots has undergone great changes of late years, it is obviously unfair to give examples from old sources, and the only available modern data suitable for the comparison are given in Kirkaldy's experiments on Fagersta steel in 1873, Series C3, representing the presence of 0·15 of carbon, from which is extracted Table B. The lowest breaking strain is 23·6 tons per sq. in., and the highest 27·1 tons; the least degree of contraction of area at the point of fracture is 31·4 per cent., and the greatest 72 per cent.; the least degree of extension, over a length of 10 in., is 20·2 per cent., and the greatest 31·1 per cent. Numerous samples of wrought iron of higher breaking strain, and some few with an equal contraction of area and the same degree of ultimate extension, can be found, but probably not of all the three combined, when a sufficient amount of work has been expended upon the steel to make it truly homogeneous, as in the first two or three tests given in the table.

Puddling may be shortly described as a process for the conversion of cast iron, containing from 3 to 10 per cent. of impurities, into wrought iron, containing in its first stage as puddled iron from $\frac{1}{2}$ to 3 per cent. Oxygen is the almost universal agent employed for this purpose, and is obtained principally from oxide of iron in various forms, technically termed fettling. The furnace in which the operation is performed may be considered as consisting of four parts—the grate, the hearth, the flue, and the chimney; but frequently one chimney serves for a number of furnaces. The grate need not be further noticed, except to state that where iron of superior quality and requiring to be kept very clean is produced, it is fixed lower than usual, to prevent coal or ash from passing over to the hearth. The hearth of a puddling, or more correctly speaking, boiling furnace, is made of cast-iron plates, which are kept cool by various means to prevent them from melting with the intense heat, and are also covered with oxide of iron or fettling, which is renewed from time to time as required. Usually a heat of $4\frac{1}{2}$ cwt. long weight, or 540 lb., is charged along with some cinder from the hammer or rolls. As soon as the iron begins to melt, it comes in contact with the fettling and cinder in a solid or liquid condition. Chemical action between the two is immediately set up, so that the first melted iron has a greater chance of purification than that melted at a later stage. All round the sides of the hearth the fettling rises some inches above the floor, and as the tools are worked backward and forward and from side to side the melted iron is washed up against it, and therefore the outer portions of the iron are exposed to more fettling than the rest, and begin to thicken first. The puddler scrapes the thick iron into the middle and mixes it thoroughly among the other. The thickening is helped on by the closing of the damper, which is generally done as soon as the iron is properly melted; and when the iron and cinder are well mixed together, the boil generally commences and the damper is raised. As the boil proceeds, the most advanced portions sink to the bottom, and are brought up again and blended with the rest by the puddler's tools. After the melting, mixing, and boiling, comes the dropping as it is called,

when the ebullition gradually subsides, till the whole mass lies upon the floor of the hearth in a pasty state. The floor of the hearth is much colder than the upper portion, all the heat being derived from above, so that the action of the fire comes very unequally upon the iron, which is worked up by the puddler, and turned over and broken into small pieces to allow the flame to play upon all parts as uniformly as may be, the damper being lowered at the same time; but as the tools are only very small in proportion to the quantity of iron, and the puddler's strength and activity limited, it is easy to see that at best the working of the iron is only imperfect. Next comes the balling, or making into lumps suitable for the hammer, which is done as expeditiously as possible, putting together the most advanced portions first. But even here perfection in hitting the right moment with the whole of the iron in the furnace is scarcely attainable; so that there are at every stage causes making against homogeneity, which it requires all the best efforts of the workman to keep in check. These causes are increased sometimes by the furnace working with the flue slanting upwards directly into a firebrick chimney, the brickwork of which gradually melts away, and theoretically should come into the furnace, heat by heat, in which case little harm would be done; but in practice the puddler keeps it back by the fettling, and now and again it runs into the furnace all at once, and in many cases spoils a heat. Frequently the effect is to produce fibre, by the diffusion of a thick cinder throughout the mass, preventing the formation of crystals, but the iron is generally weak and red-short. When a short flue is carried from the furnace to a boiler, the quantity of melted brick is scarcely worth notice.

So far this is a dark picture of puddling; but fortunately there is a counterbalancing principle at work, which greatly mitigates the evils. Pure iron appears to be soft and ductile, strength is added to it by the presence of carbon, and speaking generally it may be said that iron is good so far as it is free from all other elements, excepting perhaps manganese. But carbon, though a most valuable accompaniment of pure iron, seems to be highly injurious in connection with phosphorus and silicon in quantity. These

elements, which along with other foreign matters impart fluidity to iron, first of all appear to reduce the amount of carbon in the pig; such iron comes readily to the boil, and the liquid condition being maintained by the presence of the other impurities, the boil may be prolonged to a later stage of decarbonisation than can be done with better iron: hence it is possible to reduce the carbon to a mere trace by well and careful working, and to make the iron soft, fibrous, weldable, and apparently very good, though it has never yet been proved equal in all respects to that produced from a higher quality of pig. The ordinary expression applied to it by consumers of first-class iron is that it wants "body," which appears to mean neither more nor less than that it lacks strength, is not sufficiently pure, and is short of carbon. But when all other elements are reduced to a very slight percentage, the carbon is pretty certain to be unusually high, and the iron when broken suddenly by a smart blow upon the anvil after cutting through the skin is almost invariably crystalline or granular, though really capable of bearing a high tensile strain, contracting very much at the point of fracture, and elongating considerably; when not broken suddenly, the appearance is fibrous, and the fracture under tensile strain is generally all fibrous. Such iron must be good, despite its crystals, and as it improves with working, it is better in the manufactured article than in the bar; while iron made fibrous by a mixture of strong cinder, and working comparatively cold in the finishing heat to prevent this cinder escaping, is never equal in point of strength and ductility to the other, and is very apt, with the least degree of overheating by the smith, to become extremely brittle.

The writer has observed many of these phenomena for years past, but they have never come out so forcibly as in the course of some experiments that he has had in hand for several months, undertaken with a view to ascertain the properties of several kinds of iron, chiefly from hæmatite ores, in constant use at the works of his firm, and gaining incidentally some knowledge of the principles of puddling and the nature of iron generally. There was no intention at the time the trials were made of publishing

the results, and they are not to be looked upon as anything out of the usual course. The heats given were all of full weight, no extra time was spent over them, no extra fettling used, and no additional heat was employed to purify the iron to a greater extent than was likely to be done in actual every-day work. Occasionally the puddler, in his anxiety to do well, would step beyond these bounds; but such heats were always rejected for tests and analysis, because it was well known that the results would be entirely delusive. The puddled blooms were rolled into bars without reheating, and finished at a second heat, except four of the samples, the results of which are represented in Tables E and F.

Table C gives the tests of four bars of Marron iron of various sizes and shapes, from four different puddled bars of one heat. The ultimate stress ranges from 24 to 27·3 tons per sq. in.; the contraction of area from 40 to 52·4 per cent.; the extension, taken over a length of 10 in., from 22·1 in the smallest size to 24·2 per cent. in the largest. There was considerable difference between the properties of the first and the last of the four, and an analysis of each was taken—(the first and second of Table F)—the last being highest in carbon, and probably, from the greater total percentage of the various elements, lowest in cinder.

In Table D the first four samples represent two puddled bars of the same heat. One piece was taken from the end and the other from the middle of each finished bar. The samples range from 24·1 to 26·9 tons per sq. in. ultimate stress, from 32·8 to 46·7 per cent. contraction, and from 22·7 to 26·2 per cent. extension over 10 in. length. The first of this list presented the unusual feature of being worst welded in the middle of the bar, caused by the pile being charged after the rest, and drawn before the heat had permeated throughout. When fractured, it exhibited the five pieces of the pile very distinctly, though the end of the bar was well welded. An imperfect weld reduces a bar to a series of flat plates, and it is well known that plates neither contract at the broken part nor elongate so much as rounds and squares.

Table E and the last five items of Table F give the results of the most important trial of all, because they represent the whole of a

puddled heat both in tests and analyses. The sizes of iron are all the same, which is better for comparison with each other. The breaking strain is from 23 to 25 tons per sq. in.; the contraction from 31·6 to 50 per cent.; the extension, over 10 in. length, from 20·1 to 26 per cent. An effort was made in this heat to get the carbon lower than before, and it gave an average of carbon 0·131 per cent., against an average of 0·175 per cent. in C and D; but the sum of the phosphorus and silicon had risen from 0·133 to 0·243 per cent., and it will be seen that in F itself as the carbon falls the phosphorus and silicon increase. Thus—

		Carbon.		Phosphorus and Silicon.	
W.R.3	contained	0·180	per cent.	0·093	per cent.
W.T.W.	„	0·150	„	0·260	„
W.5	„	0·115	„	0·310	„
W.R.5	„	0·090	„	0·345	„

W.S. is here omitted, because it was treated in an entirely different manner from the rest, by which the cinder was better extruded, and it is not therefore eligible for comparison, because some of the phosphorus and silicon appearing in the analysis of iron properly belongs to the cinder remaining in it.

Attention is requested to this point, because it is susceptible of a practicable application specially concerning engineers. There is a probability that these oscillations of carbon on the one hand and phosphorus and silicon on the other are not accidental, but are really cause and effect. A considerable amount of carbon often remains in the partly puddled iron after it has reached a spongy condition, and the cavities of it are filled with cinder, which generally contains a good deal of phosphoric acid and silica. It is likely that some of the oxygen for the removal of the carbon is obtained from this cinder, and that it sets free iron, phosphorus, and silicon, which are added to the puddled ball. Colouring is lent to this supposition by the behaviour of puddled iron at the hammer, by the effect of a puddled heat waiting in the furnace after it is made into balls, and by the composition of puddled-ball cinder. Frequently a slight flame is observed from a puddled ball, and when the hammer drops upon it and the cinder is thereby brought into closer contact with the iron, it is immediately covered with the

flames of carbonic oxide. When the puddled balls remain too long in the furnace, the quality of the iron is greatly impaired; though the causes of this do not appear to have been investigated, it is a well-known fact. It may be that occluded gases have something to do with it, as well as the cause just referred to. Cinder expelled from puddled balls, as far as the writer has been able to examine it, is invariably poorer in iron and richer in silicon and phosphorus than the cinder left in the furnace at the time the balls are withdrawn.

Without attempting to trace any very close connection between the mechanical properties and the chemical composition of the different samples given in Tables C, D, E, and F, attention may be very properly drawn to one fact which comes out with remarkable clearness. It has frequently been contended in making tests that the true value of any iron is shown by the amount of stress at the fractured area, and there can be no doubt that this shows its real strength. It will be found throughout that as the carbon increases so does the stress per sq. in. at the fractured area. Thus—

Carbon.	Stress at Fractured Area.	Original Area.
0·090 per cent.	92,595 lb. per. sq. in.	0·442 sq. in.
0·115 „	94,308 „	0·442 „
0·120 „	94,501 „	0·442 „
0·150 „	94,916 „	0·442 „
0·165 „	102,809 „	0·255 „
0·170 „	101,626 „	0·785 „
0·180 „	103,457 „	0·442 „
0·190 „	112,738 „	0·265 „

The apparent exception in the case of 0·170 per cent. is due to the area being three times as great as in 0·165, and therefore having a much less amount of work put upon it, and the immense increase of strength from 0·180 to 0·190 is mainly accounted for by the extra work put upon the latter.

It has been stated previously that a mixture of iron and cinder is not compatible with homogeneity. The great capacity for heat possessed by iron of unusual purity gives better facilities for expelling the cinder, besides which it does not stick in such iron so pertinaciously as in that of lower quality.

Of the analyses presented in Table G, the first, second, and fourth represent a description of iron very much in favour for years past, soft in its hot as well as in its cold state, easy to weld, and fibrous. The third was similar, but not entirely fibrous; it has been added just to show the influence of carbon along with silicon and phosphorus in quantity. It will be seen that all the four are much lower in metallic iron than the previous samples, and that the total percentages are also lower. Ordinary chemical analyses do not distinguish between iron and its oxide—it is all given as iron, whereas there may be $\frac{1}{2}$ per cent. or more existing in combination with oxygen; and the weight of oxygen not being given, this causes the total percentage to fall short in the more impure article.

From what has already been advanced, the true means of ensuring such a degree of homogeneity as is possible by puddling appear to lie in the production of iron as pure as may be with its attendant carbon; and it is believed that if iron were puddled with a view to the best possible quality and the greatest degree of homogeneity without any regard to the presence or absence of fibre, the carbon would run still higher than in Table F, and that the iron would be more valuable in every way if its properties were appreciated and its peculiarities understood. Iron makers have a perfect right to ask that restrictions should not be imposed upon them which are not imposed upon makers of so-called steel. If it be true, as it appears to be from the foregoing observations, that the most valuable iron is that which is purest, along with sufficient carbon to impart strength, it is obviously bad policy to replace carbon by phosphorus and silicon, even though that replacement should be accompanied by the substitution of fibre in a nicked and suddenly broken sample for fine crystal or grain; and it is not impossible that such engineers and consumers of iron as frown upon everything in the shape of wrought iron which is not fibrous, have gone in the direction of the opposite extreme to certain of their predecessors of thirty years ago, who were very apt to designate fibre by the contemptible name of "dirt."

Having now considered the "boiling" process, as usually practised, the best Yorkshire system will next be touched upon, as

carried out at Low Moor Iron Works, which is, as before intimated, the old puddling process. This system appears to be a constant fight for homogeneity from first to last. Only the very best materials are used throughout. The iron is all refined, and it is puddled in heats of only 370 lb., which can be manipulated much more thoroughly than the larger quantity before mentioned. The very best workmen are employed, an efficient check is kept upon the work of each, and he is paid according to the quality turned out, and altogether the method seems to be the best that can be devised for ensuring the highest degree of homogeneity possible by puddling.

Mechanical rabbles are now worked only to double furnaces, having two doors opposite each other, a rabble being placed to work through the stopper-hole of each; but these furnaces, as usually constructed, are objectionable in several respects. In the single furnace, the roof is made highest over the door, as shown at A in Fig. 1, Plate 1, to counteract the effect of the air drawing in at the working hole and at the crevices about the door and door-frame, which contrivance brings the flame tolerably well to the front; but the double furnaces are highest in the middle, as shown at B in Fig. 2, and the flame is not therefore so well equalised. This style of construction may be a necessary evil, but it is worth attention to try to amend it. The depth of the hearth below the fore-plate upon which the door rests, and which serves as a support for the puddler's tools and as a fulcrum whenever leverage is required, is generally greater than in a hand furnace, in order to prevent iron and cinder being raked out by the motion of the rabbles; this causes the workman extra labour when he is obliged to work without the machine, which is a longer period than the machining, so that there is a per-contra to the saving of labour by the machine. The double furnaces, having no backwalls, have of course much less brickwork and fettling in proportion to the charge of iron than single furnaces. the results of which are saving of fuel and of fettling; but the furnaces, having a smaller reservoir of heat in the absence of the backwalls, work more slowly and do not regain their full temperature so soon after having been cooled down for any purpose, such as cleaning

the grate or lowering the damper to bring on the boil. This is a great drawback in working iron that requires a good deal of dampering and the heat restoring rapidly after the damper is raised. The saving of fettling when there are a few of such furnaces, in what may be termed the experimental stage, among a number of the ordinary kind, is often made up by a free use of mill scale (of course depriving the rest of their fair share), and by the oxidising of a larger quantity of scrap to keep the bottom good. When not so made up, a better mixture of iron must be resorted to, or more waste of iron will be incurred, or else worse iron will be made, that is of course always supposing that the mixture of iron and the quantity and kind of fettling are properly adapted and adjusted to each other in the single furnaces. Double furnaces sometimes work hotter on one side than on the other, which is vexatious, for the damper occasionally wants lowering to suit the condition of the iron on one side and keeping up to suit it on the other side, but as the same damper generally acts for both this cannot be done. It also happens now and then that the wind blows in strongly at one stopper-hole and drives the flame out at the other, to the annoyance and inconvenience of the workmen. The Pickles machine at Kirkstall Forge, near Leeds, is perhaps the best of its class, but there is not apparently anything about the system of mechanical rabbling generally to give grounds for expecting a greater degree of homogeneity in iron made by this than by the ordinary methods, though double furnaces unquestionably save fuel.

The Casson-Dormoy furnace, with Casson's gas-producer, at Round Oak Iron Works, Dudley, has a grate much wider than the hearth, which is circular, and the furnace appears to keep pretty well filled with flame. A heat of 10 cwt. was puddled in the writer's presence in 80 minutes from the time of being charged at a red heat to the withdrawal of the last ball. The heat was physicked, and the produce was 9 cwt. 2 qr. 2 lb. of strong granular iron or steel, but the bars were not all exactly alike, though there was a wonderful amount of regularity. The men worked most vigorously, as the puddlers of the district know how to work. The sweep of the machine did not seem to be perfectly adapted to the form of the furnace;

to remedy this the men gave the rabble a side push when it came to the jambs, but as this might not always be attended to, probably a little alteration of the machine is desirable to remove the necessity for it.

The Maudslay or Pernot furnace, the floor of which is upon an inclined plane and which rotates in this position, is an advance upon the foregoing, because it exposes the iron alternately to the action of the cinder when it comes to the lowest part and then to the flame of the furnace without the covering of cinder; but there is still the disadvantage of the colder bottom, and of turning over and balling by manual labour.

The form of furnace revolving on a horizontal axis appears to give the greatest promise for the future, if those who employ it will only study chemical action and work according to it, instead of trying to overcome their difficulties by merely mechanical contrivances. When iron is charged cold into these furnaces the evils pointed out in the ordinary furnace are intensified, because a greater quantity of melted fettling is present, but the iron ought always to be charged liquid. The working of the iron while it remains liquid is far more thorough than in the best of the other systems noticed, but when the iron becomes pasty there is no means of opening it out as is done by a good puddler, and consequently the advantage is to some extent lost in the latter portions of the heat.

The published reports on the Danks furnace do not give much promise of homogeneity, inasmuch as from various causes, including imperfect working of the puddled ball, there has been generally a large quantity of very thick cinder present, difficult to expel.

The Spencer furnace shows considerably better results from its working than the Danks, that is from a metallurgical point of view; but there is some reason to fear that the degree of heat likely to be obtained, owing to the thinness of the lining, would hardly be sufficient for the proper expulsion of the cinder without reheating, and this it will be readily understood, from the considerations previously advanced, is objectionable, in the presence of much impure cinder. From the smaller quantity of fettling used it may be inferred that the cinder would not be so thick as in the Danks

furnace, and therefore better to expel. This is however rather touching upon a moot point, as it is held by some that less fettling is used in the Danks furnace; but as none have yet had the courage to give the quantity of fettling over a year's work in this country, as has been done in reference to the Spencer furnace, the opinion, which is based largely upon probabilities deduced from the construction and method of working the two furnaces, cannot be expected to carry much weight. In the Spencer furnace the difficulties appear to have been largely mechanical, and here again, as in the building of the double furnaces, is a case in which engineers might help.

The Crampton furnace, assisted by the equable character of its flame and the means afforded of keeping it in perfect command, would seem to give the greatest promise of any in the direction of homogeneity. Though the amount of fettling used is very great, the purification of the iron is most extraordinary, and such purification has been shown to be one of the conditions favourable to homogeneity. Further, when the coal is suitable the cinder is thinned by the silica from the ash, and the bulk of it can be easily driven out of the iron. But to make the best use of the furnace, the finely crystalline iron before spoken of should be aimed at, and it should not be condemned when made because it is not known by the name of steel.

Now with respect to the subsequent operations, the much-abused puddled-bar system is really the outcome of an effort to obtain uniformity, the causes making against which in puddling have already been dealt with. Probably it was thought at first that rolling the puddled iron into flat bars, cutting up, and piling would divide the irregularities by the number of pieces in the pile, as well as improve the iron by putting more work upon it. But it does more than this: any iron not properly worked, when rolled off from the puddled bloom without reheating, tears into holes of various sizes, from the smallest speck upwards, by the action of the rolls; and when the pile is subjected to the heat of the furnace, these holes allow the raw places to receive a greater share of the heat, and they act as receptacles for cinder melting off the iron,

both of which tend to purify it in a high degree, for it must be remembered that this cinder is much superior to that in the puddling furnaces. Another advantage is that any badly puddled iron shows crystal in cutting cold at the shears into the lengths required for the pile, and can be thrown out. The very great irregularities in the samples of hoop iron given in Table A may be largely accounted for by the fact that they were rolled from billets, being too small a size to make out of piles.

Table E exhibits five different methods of working. The first upon the list, W.S., was worked out of the solid in the style advocated by Mr. Crampton, and though it is the highest in breaking strain, and the three samples were all from the same puddled bar, it yet shows the greatest amount of difference in this respect of any of the samples. W.T.W. was rolled off into puddled bars, piled and rolled again into flat bars, which were again piled and finished at a third heat. It will be seen that it varies least of any in ultimate strength, from the different parts being so well blended. W.5 was rolled from five pieces of puddled bar without reheating, just as in the ordinary way, and except in the item of elongation it gives superior results to W.R.5, in which the only difference is that the puddled bloom was reheated before rolling. If it be objected that the analysis of W.5 (in Table F) indicates better quality, it may be answered, that is only an exemplification of the lowering of carbon and the increase of phosphorus and silicon (and in this case of sulphur also), by the exposure to heat of iron containing impure cinder. W.R.3 was well hammered twice and piled only three high, so as to have fewer welds. Taking the contraction of area, which is 50 per cent., and the extension 25·8 per cent. over 10 inches length, along with the breaking strain of 23·1 tons per sq. in. of original area, it is the best given in the table; but as the analysis is also superior to any of the rest, it would probably be misleading to attribute its superlative excellence to the method of working.

In conclusion, the writer begs to apologise for the imperfection of his endeavours to elucidate this subject in the limits of the present paper; but he hopes that some little light will have been thrown

upon this most interesting subject, and that his remarks will not be without their use in enabling the members better to understand the position of those who supply their chief constructive material, and in acquainting them with some of the difficulties necessarily encountered in the manufacturing operations, so that they may be able to form a more correct notion as to what it is reasonable to expect at the hands of the makers.

TABLE A.

TABLE A.

Tests of Hoop Iron and Steel.

(*Pearson and Knowles Coal and Iron Co., W.I.W., Warrington.*)

Hoops 1 in. × 18 w.g.

STEEL.			IRON.		
No.	Breaking Weight.	Elongation.	No.	Breaking Weight.	Elongation.
	Lbs.	Per cent.		Lbs.	Per cent.
1	4,360	11·50	1	2,660	9·00
2	3,800	13·25	2	2,420	4·50
3	4,275	13·00	3	2,525	9·25
4	4,100	13·50	4	2,400	1·25
5	4,100	11·00	5	2,480	4·00
6	4,200	9·50	6	2,000	3·00
7	3,700	12·00	7	2,300	2·50
8	4,445	10·50	8	2,000	4·00
9	3,680	14·25	9	2,490	9·25
10	4,430	8·75	10	2,300	3·50
11	3,800	15·00	11	2,790	9·75
12	4,300	10·50	12	2,200	2·00
13	4,000	11·75	13	2,400	7·50
14	4,750	12·25	14	2,210	3·00
15	4,200	13·00	15	2,870	8·00
16	3,700	9·50	16	2,400	3·25
17	3,720	14·75	17	2,650	3·50
18	3,815	15·00	18	2,500	9·75
19	3,770	10·25	19	2,400	1·50
20	3,700	12·50	20	2,375	4·50
Average	4,042	12·08	Average	2,388	5·15

TABLE B.

Tests of Fagersta Steel Bars, by D. Kirkaldy, 1873.

Bars 10 in. length.

Size of Bars.	Specimens turned to		Ultimate Stress per sq. in. of Original Area.		Contraction of Area at Fracture.	Ultimate Extension.	Appearance of Fracture.
	Diam.	Area.					
Inch.	In.	Sq. in.	Lbs.	Tons.	Per cent.	Per cent.	
½ square	0·357	0·100	60,780	27·1	72·0	22·2	All Silky
1 do.	0·619	0·300	54,560	24·4	69·7	27·8	do.
1½ do.	1·009	0·800	57,960	25·9	56·0	27·3	do.
2 do.	1·382	1·500	57,453	25·6	51·8	28·6	95 per cent. Silky
2½ do.	1·694	2·250	57,345	25·6	31·4	20·2	All Granular
3 do.	1·994	3·000	52,962	23·6	57·8	31·1	All Silky
		Average	56,843	25·4	56·45	26·2	

TABLE C.

Tests of Marron Iron Bars, by D. Kirkaldy, 3 July 1876.

(Chiefly from Mossbay Hæmatite.)

Bars 10 in. length.

Size of Bars.	Original Area.	Ultimate Stress per sq. in. of Original Area.		Contraction of Area at Fracture.	Stress per sq. in. of Fractured Area.	Ultimate Extension.	Appearance of Fracture.
Inch.	Sq. in.	Lbs.	Tons.	Per cent.	Lbs.	Per cent.	
$\frac{9}{16}$ diam.	0·255	61,282	27·3	40·3	102,809	22·1	Fibrous
$\frac{9}{16}$ square	0·331	55,791	24·8	42·9	97,709	23·0	do.
¾ do.	0·570	54,894	24·5	40·0	91,491	24·2	do.
½ do.	0·265	53,603	24·0	52·4	112,738	22·9	do.

TABLE D.

Tests of Marron Iron Bars, by D. Kirkaldy, 24 July 1876.

(Chiefly from Mossbay Hæmatite.)

Bars 10 in. length.

Diameter of Bars.		Original Area.	Ultimate Stress per sq. in. of Original Area.			Contraction of Area at Fracture.		Stress per sq. in. of Fractured Area.	Ultimate Extension.		Appearance of Fracture.
Inch.		Sq. in.	Lbs.	Lbs.	Tons.	Per cent.		Lbs.	Per cent.		
$1\frac{1}{8}$ diam.	M	0·968	60,351	59,584	26·6	32·8	37·1	94,786	22·7	23·3	Fibrous.
$1\frac{1}{8}$ do.	E	do.	58,817			41·4			24·0		do.
1 do.	E	0·785	54,203	54,114	24·1	46·7	46·7	101,626	26·1	26·1	do.
1 do.	M	do.	54,025			46·7			26·2		do.
$1\frac{1}{8}$ do.	M	0·968	52,747	52,564	23·5	44·1	44·7	95,191	26·5	25·8	do.
$1\frac{1}{8}$ do.	E	do.	52,381			45·4			25·2		do.

(M middle of bar, E end of bar.)

TABLE E.

Tests of Marron Iron Bars, by D. Kirkaldy, 31 August 1876.

(*Chiefly from Mossbay Hæmatite.*)

Bars 10 in. length.

Description of Iron.		Original Area.	Ultimate Stress per sq. in. of Original Area.			Contraction of Area at Fracture.		Stress per sq. in. of Fractured Area.	Ultimate Extension.		Appearance of Fracture.
		Sq. in.	Lbs.	Lbs.	Tons.	Per cent.		Lbs.	Per cent.		
W.S.	M	0·442	56,515			42·3			24·1		Fibrous
do.	M	do.	56,470	55,803	24·9	40·2	40·9	94,501	22·6	23·3	do.
do.	E	do.	54,423			40·2			23·1		do.
W.T.W.	M	do.	55,791			46·1			24·1		do.
do.	M	do.	55,723	55,680	24·8	46·1	41·3	94,916	23·8	23·0	do.
do.	E	do.	55,554			31·6			21·1		do.
W.5	M	do.	55,780			42·3			23·9		do., 5 p. c. crystalline
do.	E	do.	55,361	55,048	24·6	40·2	41·6	94,308	20·1	22·1	Fibrous
do.	M	do.	54,004			42·3			22·3		do.
W.R.5	M	do.	55,226			46·1			24·8		do.
do.	E	do.	55,181	54,747	24·5	38·2	40·8	92,595	22·6	23·2	do., peculiar
do.	M	do.	53,834			38·2			22·3		do., do.
W.R.3	M	do.	52,138			50·0			25·9		Fibrous
do.	M	do.	51,961	51,728	23·1	50·0	50·0	103,457	26·0	25·8	do.
do.	E	do.	51,085			50·0			25·5		do.

(M middle of bar, E end of bar.)

TABLE F.

Analysis of Marron Bar Iron, by G. F. Downar, Workington.

(Chiefly from Mossbay Hæmatite.)

Size of Bars.	Description.	Iron.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Total.
Inch.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
$\frac{9}{16}$ diam.	...	99·533	0·165	0·067	0·011	0·075	Trace	99·851
$\frac{1}{2}$ square	...	99·530	0·190	0·074	0·010	0·091	Trace	99·895
1 diam.	...	99·533	0·170	0·047	0·011	0·045	Trace	99·806
$\frac{3}{4}$ do.	W.S.	99·498	0·120	0·116	0·015	0·091	Trace	99·840
$\frac{3}{4}$ do.	W.T.W.	99·326	0·150	0·128	0·012	0·132	Trace	99·748
$\frac{3}{4}$ do.	W.5	99·500	0·115	0·149	0·011	0·161	Trace	99·936
$\frac{3}{4}$ do.	W.R.5	99·498	0·090	0·163	0·022	0·182	Trace	99·955
$\frac{3}{4}$ do.	W.R.3	99·704	0·180	0·019	0·014	0·074	Trace	99·991

TABLE G.

Analysis of Bar Iron.

(Ordinary qualities.)

Size of Bars.	Description.	Iron.	Carbon.	Silicon.	Sulphur.	Phosphorus.	Manganese.	Total.
Inch.		Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
$\frac{3}{4}$ diam.*	K.B.W.	98·625	Trace	0·258	0·052	0·321	Trace	99·256
$\frac{3}{4}$ do. *	do.	98·983	Trace	0·174	0·038	0·289	Trace	99·484
$\frac{5}{8}$ do. *	do.	99·064	0·075	0·224	0·035	0·310	Trace	99·708
$1\frac{1}{4}\times\frac{1}{2}$ †	K.B.W. Best	99·115	Trace	0·170	0·028	0·200	0·140	99·653

(Analyst, * Downar, † Pattinson.)

The consideration of the Paper was adjourned to the next Meeting.

The Meeting then terminated. In the evening a number of the Members dined together in celebration of the Thirtieth Anniversary of the Institution.

Fig. 1. *Single Puddling Furnace.*

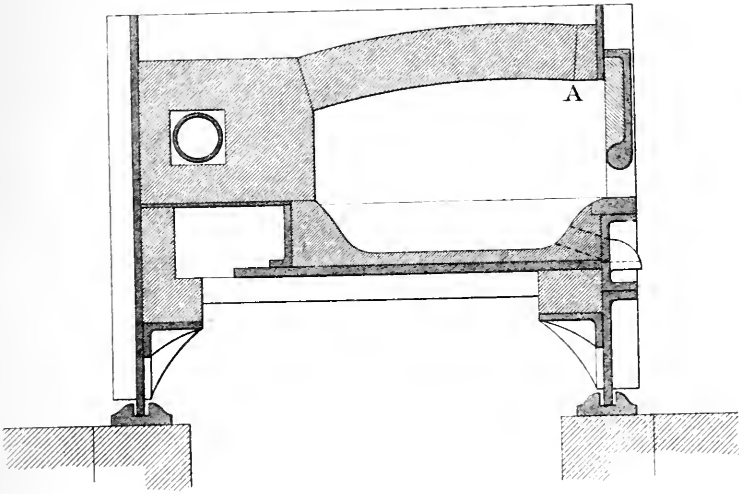
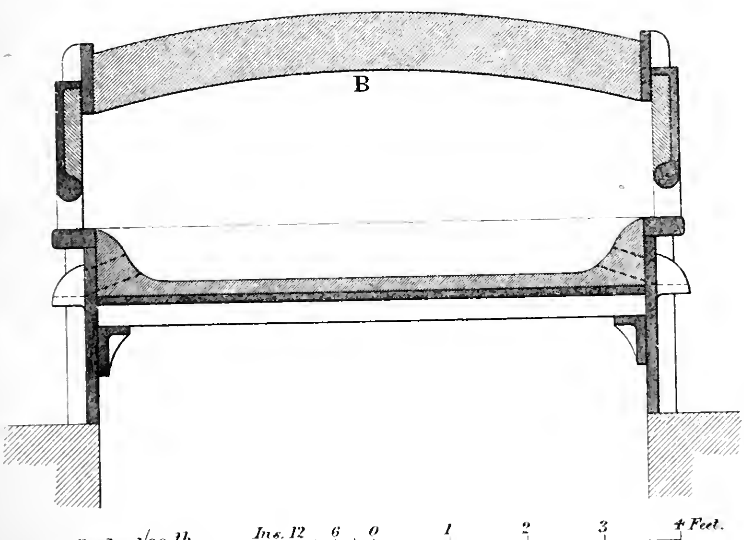


Fig. 2. *Double Puddling Furnace.*



Scale 1/30 th

(Proceedings Inst. M. E. 1877.)

PROCEEDINGS.

May 1877.

The Spring Meeting of the Members was held at the Institution of Civil Engineers, London, on Thursday, 31st May, 1877; Thomas Hawksley, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

Stephen Alley,	Glasgow.
Manfred Powis Bale,	London.
Thomas Oldham Bennett,	Manchester.
Robert William Peregrine Birch,	London.
Samuel Buckley,	Oldham.
Clerke Burton,	Cardiff.
Robert Carr,	London.
Claude Carter,	Manchester.
John Chisholm,	Leeds.
Henry Coley,	London.
Rookes Evelyn Bell Crompton,	Chelmsford.
William Dawson,	Birmingham.
James Gibson Dees,	Whitehaven.
Arthur Loft Dossor,	Hull.
Charles Ralph Dübs,	Glasgow.
Henry John Sillars Dübs,	Glasgow.
James Fenton,	Leeds.
James Fortescue Flannery,	London.
John Hazell Fraser,	London.
William Wallington Harris,	London.

THOMAS HOWARD HEPWORTH, . . .	Derby.
JOSEPH HOPKINSON, ...	Huddersfield.
SAMUEL EARNSHAW HOWELL, . . .	Sheffield.
WALTER HUNTER, ...	London.
JOHN WILLIAM HENRY JAMES, . . .	London.
WILLIAM JONES, ...	Manchester.
ARNOLD LUPTON, ...	Holywell.
WILLIAM BAYLEY MARSHALL, . . .	Bridgwater.
HENRY MERRYWEATHER, ...	London.
DONALD NICOLSON, ...	Bombay.
WILLIAM HENRY PANTON, ...	Stockton-on-Tees.
JOHN CARTER PARK, ...	London.
JOHN McCLURE CALDWELL PATON, . .	Java.
THOMAS FRANCIS PIGOT, ...	Dublin.
WILLIAM CREES TAYLOR, ...	Liverpool.
WILLIAM THOM, ...	Blackburn.
FREDERIC WILLIAM THORNTON, . . .	Hull.
JAMES WALTON, ...	London.
JOHN WAUGH, ...	Bradford.
HENRY JOHN WORSSAM, ...	London.
FREDERIC CHRISTOPHER WYVILL, . .	Leeds.

ASSOCIATE.

ENRIQUE DE VIAL, ...	Santander, Spain.

The PRESIDENT announced that the Summer Meeting would be held at Bristol, on Tuesday 24th July and following days, in consequence of the occurrence of the Assizes at the time previously proposed for the Meeting.

The PRESIDENT also announced that a Committee of the Council had been appointed for the purpose of arranging for the early occupation of premises in Westminster, that were deemed by the Council to be suitable for the accommodation of the Institution.

The discussion of Mr. Kirk's paper on "Homogeneous Iron" communicated at the previous meeting (see Proceedings January 1877 page 48) then took place.

ON HOMOGENEOUS IRON, AND THE DEGREE OF HOMOGENEITY TO BE EXPECTED IN IRON PRODUCED BY VARIOUS SYSTEMS OF PUDDLING AND SUBSEQUENT WORKING.

By Mr. HENRY KIRK, of Workington.

(*Discussion.*)

Mr. Kirk remarked that he wished to draw attention to three of the positions taken up in the paper, which were of general interest, whatever might be the form of furnace employed in the manufacture of iron; and also to show what had occurred to confirm those positions or otherwise since the communication of the paper at the previous meeting, since which a paper had been read elsewhere by Mr. I. Lowthian Bell "on the separation of carbon, silicon, sulphur, and phosphorus, in the refining and puddling furnace and in the Bessemer converter;" * and another paper bearing on the subject of his own had been read by Mr. Stead of Middlesbrough, analytical chemist.†

The first position taken up in his own paper was that homogeneous iron, or mild steel as it was generally called, was the very best form of iron, and the nearer it could be approached in puddled iron the more valuable would be the product; but there was a difficulty in the way of its manufacture and use, owing to the requirements of some engineers who did not believe that wrought iron could be good, unless it showed a fibrous fracture when tested by cutting through the skin and breaking over the anvil by the blows of a hammer. Two instances of this kind had come under his notice within the last few months. In the first, a number of nicked and broken rivets

* See Proceedings of Iron and Steel Institute, March 1877.

† See Proceedings of Cleveland Institution of Engineers, March 1877.

showing steely fractures having been returned to his own works, he had requested that the iron from which they were made should be tested by the senders for tensile strain; the tests gave 25 tons per sq. in. as the tensile strength, and the elongation was over 25 per cent. on an original length of 1 ft., thus showing an extraordinarily good quality of iron; but notwithstanding this it was rejected by the inspector. In a second similar instance, in which the users were requested to test a riveted joint, they had declined to give any information about the tests, but they had immediately ordered a further supply of the same quality of iron, and had continued to order it since.

The second position maintained in the paper was that, as puddling was an operation in which the iron was formed in a pasty condition, and as in any furnace yet invented the charge was not exposed throughout every portion to the same purifying action, it was perhaps impossible to ensure perfect homogeneity; but this evil appeared to be much lessened by a counteracting influence at work in the furnace itself. Carbon, silicon, and phosphorus, all gave hardness to iron; carbon, along with hardness, gave strength, while silicon and phosphorus were said to impart brittleness. In the experiments brought forward in the paper it was seen that, as the proportion of carbon in the iron ran higher, silicon and phosphorus ran lower; and that, as carbon was removed in the later stages of puddling, silicon and phosphorus increased. In Mr. Bell's recent paper, already referred to, it had been shown there was considerably more carbon in Bowling and Carinthian pig which were low in silicon and phosphorus, than in Cleveland pig which was high in these elements; and that under treatment in the refinery carbon was eliminated nearly twice as much from Clarence pig, which was a Cleveland brand, as from Bowling. Also that in puddling Clarence pig, when a large quantity of phosphorus was left in the iron, the carbon was *nil*; but with only half the quantity of phosphorus, the carbon rose to 0·071 and 0·184 per cent. Allusion had further been made in Mr. Bell's paper to the irregularity found in the same heat puddled by the same man, as shown also in his own paper; and an illustration was given of the uniformity with which the Danks furnace was

capable of doing its work, showing 0·179 per cent. of phosphorus in the centre of a rail made from one solid bloom, and 0·178 and 0·176 per cent. respectively in the two ends of the same rail. It would thus appear that, contrary to the opinion expressed in his own paper, the Danks furnace gave far more uniform results in the same heat than the ordinary puddling furnace; and he had no doubt that, when steely iron was produced, that was actually the case. The rotary furnace seemed to be peculiarly well adapted to the manufacture of steely iron, because as the iron came to "nature" as it was technically called, it gathered into one or more lumps, the portions first ready being in the middle of the mass, and other portions being added to the lump as soon as sufficiently advanced; hence the uniformity of quality. But when the process was carried beyond that stage the advantage was lost, the outer portions being exposed to the action of the flame and of the cinder lying in the furnace, from which the inner portions were protected. An experiment had been made to test the uniformity of Danks iron when carried forward to the fibrous stage: a $\frac{3}{4}$ inch round bar about 16 ft. length, though comprising less than 1-30th part of a heat, had been found on analysis by Mr. Downar of Workington to contain as great a difference as 0·243 and 0·323 per cent. of phosphorus respectively in its two opposite ends; thus exhibiting in the Danks puddling a much greater irregularity than that shown in the last five samples named in Table F of his own paper, which represented, so to speak, the whole of a heat in an ordinary puddling furnace, as compared with less than 1-30th part of a heat in the Danks furnace; and this ordinary puddle heat, it should be borne in mind, was worked specially with a view to obtain a low degree of carbon, and was therefore likely to be higher in silicon and phosphorus, and more irregular in the percentage of these elements.

The statement made in his paper that the less phosphorus there was, both in pig and in finished iron, the more carbon remained in it, had been confirmed by Mr. Stead's recent paper, which showed that carbon, silicon, and sulphur all solidified in cooling more quickly than phosphorus. Phosphorus therefore, more than any other of these elements, was capable of maintaining the fluidity of iron; so that there

was no mystery in the fact that carbon might be all worked out of iron when there was an abundance of phosphorus present, because the longer iron remained liquid the more time there was for the carbon to boil out. The researches of Mr. Bell and Mr. Stead both proved that there was a direct action between iron and phosphorus without the intervention of carbon; but it must be remembered that this action took place in the Bessemer converter and in the Siemens gas furnace at a higher temperature than was employed in ordinary puddling. It was probable however that occasionally a puddling furnace rose to the heat at which iron and phosphorus combined directly; at all events it was a well-known fact that by keeping a heat extraordinarily hot at the end of the operation in a pudding furnace the iron was greatly injured, though he was not aware that the cause of this had ever been demonstrated. It had been stated by Mr. Hopkins, in regard to the Danks process which his firm had worked at so perseveringly—and indeed so successfully during the last few months, judging from personal observation of some fifteen samples of the iron made at different times,—that "if the Danks iron when taken from the squeezer was put into the furnace, and the cinder melted out of it, the result was a large-grained cold-short iron; but if on the contrary it went direct from the squeezer to the hammer, and the cinder was hammered out of it instead of being roasted out of it, the result was close-grained iron." This pointed, according to the general notion of the effect of phosphorus, to an increase of that element in the coarse-grained iron; there would certainly be a great loss of carbon in such a case, if there were much present; and a few analyses would show whether there was a greater gain of phosphorus than could be accounted for by the eliminated carbon being replaced by phosphorus.

The third position taken up in his paper was that fibre in bar iron was frequently produced by the diffusion of a thick cinder throughout the mass, preventing the formation of crystals, or separating them from one another and thus hiding them; but cinder did not give strength, while it often caused hot-shortness and other evils. It was easy to understand that cinder might be of advantage in a very impure iron; the separation of the iron by the cinder into

different parts, as it were, gave greater power of resistance to a sudden shock. But in a high-class iron which would bend double cold when not nicked first, and would double up under an accident as the screwed bolts now exhibited had done, the retention of cinder was a great mistake. In illustration of this he might mention that some time ago there was a general demand from some of the largest customers of his own firm for a softer and more fibrous iron, on the ground that, although this meant a weaker iron, yet the iron previously supplied had always been so much above the required tests that there was no fear of its strength being too much reduced by making it softer. A softer and more fibrous iron was accordingly aimed at; and after a little practice coupled with a reduction of the hæmatite pig in the mixture of iron puddled to about one fifth of its former amount, and sometimes using no hæmatite at all in the form of pig, the desired result was obtained uniformly and regularly to the satisfaction of the consumers. But after some time had elapsed, news began to arrive of breakages in actual work of articles made from this iron, such as had never occurred with the previous make. Samples of the iron were then tested for tensile strain, when it was found that the strength was reduced 3 or 4 tons per sq. in., and that the degree of elongation and the contraction of area at the point of fracture had diminished in even greater proportions. The iron had since then been made pretty much as before, only slightly softer and more fibrous, except when it was wanted to bear a very high tensile strain, in which case it was made finely granular; and no complaints had been received but such as were clearly traceable to the soft fibrous iron, which the smiths liked so well because it was easy to work. Another evil, which appeared, in the only instances in which he had met with it, to be sometimes due to the presence of cinder in excess, was warm-shortness, or brittleness below a red heat, or at the temperature at which wood began to char. The samples now exhibited had been broken at that temperature from a $\frac{3}{4}$ inch round bar, made from iron puddled in a rotary furnace, and they were remarkable for the peculiar colours of the fracture; on analysis the iron was found to contain a large quantity of cinder, though the exact proportion had not been ascertained.

In his own practice he had found the best quality of iron to be much the cheapest; two smiths only were employed, where three had been required previously when the soft fibrous iron was being made; besides which, the breakages were not half so frequent, and the iron consequently cost actually less in the total, being less than double the price of the softer iron. There was also a great saving in fitters' wages and in wear and tear; and the turn-out was much greater, because there were fewer hindrances in replacing broken articles, and the costs and general charges were reduced in every way.

Mr. C. W. Siemens said Mr. Kirk had investigated very carefully the question of puddling, and had arrived at some definite conclusions, which were worthy of attention. With those conclusions he himself agreed generally, and also with the view that crystalline fracture in puddled iron was not antagonistic to toughness; crystalline fracture simply meant freedom from cinder, and it would be hard to demonstrate how the presence of such brittle foreign matter as cinder could ever be advantageous either to the strength or to the toughness of the iron.

The matter of puddling was one to which he had given his attention for a great number of years; and in 1868 he had read a paper before the British Association, showing that in the ordinary puddling or boiling process—not puddling in the sense in which the word was originally used—as much puddled bar ought to be obtained, or nearly as much, as the weight of pig iron put into the furnace. That view, which was then received rather with doubt by many practical iron makers, he had supported at the time by chemical argument and by experiment; but he now wished to give some working data which he had just received, confirming what he had then stated. There were at the present time thirty puddling furnaces worked by the regenerative gas firing at Messrs. Nettlefolds' Works at Wellington, Shropshire; and in reference to the results of the long experience of their working he had just received the following statement:—"As to the yield in the gas puddling furnaces, we can speak most highly from figures carefully verified in stock-taking, and the results of

eighteen months' working up to Oct. 1876 show pig metal charged into the furnaces 12,833 tons 17 cwt.; bars made 12,384 tons 19 cwt.; waste 448 tons 18 cwt., or 3·8 per cent." That was the result of the working of single puddling furnaces for a year and a half, including all the losses which occurred in practical working; and bearing that in view he thought the result was not unsatisfactory, and it verified the statement he had made in 1868. These results were confirmed moreover in the Danks furnace, where large yields were obtained simply because the charge was not much exposed to the oxidising action of the flame.

For some years past he had given his attention not so much to puddling as to the production of wrought iron from the ore direct; and simple as this problem might appear, it was one of the most difficult things to accomplish practically. He would not go so far as to say that the problem had been commercially solved, though he would say it had been practically solved after a very considerable period of trial. The ore which he had most recently experimented upon was Northamptonshire ore, which, though not rich in iron, and containing only 38 per cent. of iron, was perhaps the richest as regarded phosphoric acid, the quantity being between $2\frac{1}{2}$ and $1\frac{1}{2}$ per cent. By treating this ore, mixed generally with a certain proportion of richer oxides, in a rotary gas furnace specially arranged for the purpose, he obtained iron which when properly treated combined crystalline fracture and great toughness, and contained only slight traces of sulphur or phosphorus. Two specimens of this iron were exhibited to the meeting; one of black iron as produced from the furnace, before it was rolled into bars, but after it had passed through one reheating and hammering; and the other specimen showed the same metal rolled out into a plate of $\frac{1}{4}$ inch thickness, and bent double twice, the second time at right angles to the first, without any signs of cracking. It was seen from the first specimen that the iron had a very large crystalline fracture combined with toughness; and when the metal was rolled out, it showed no sign of cold-shortness, and was exceedingly tough. These facts showed that iron of crystalline fracture could be made tough; and there were, besides the methods mentioned in the

paper, other means by which such iron might be produced from the ore. Taking the average proportion of phosphoric acid in the Northamptonshire ore at 2 per cent., this was equivalent roughly to 1 per cent. of metallic phosphorus in an ore containing rather less than 40 per cent. of metallic iron; so that the proportion of metallic phosphorus to metallic iron would be about $2\frac{1}{2}$ per cent. in the ore, whereas in the finished iron it would perhaps be reduced to only about 0·1 per cent. As to how it was that, from ore containing so much phosphorus, the iron produced should contain so little, the explanation he would offer was, that in the ordinary process of the blast furnace the reducing action was so powerful, that not only the iron but also a portion of the silicon and all the phosphorus was deoxidised, and combined with the metallic iron; whereas in the direct process with the revolving furnace the reducing action was much less powerful, and was only just sufficient to bring the iron to a metallic condition, leaving the phosphorus still in the oxidised state. No process was therefore required for eliminating phosphorus, inasmuch as the phosphorus was never interfered with at all, the direct process simply eliminating the iron from the mixture of substances called iron ore.

Mr. I. LOWTHIAN BELL said he should like to hear from Dr. Siemens the exact nature of the influence which he supposed the presence of cinder exercised in malleable iron. The iron and cinder were generally mechanically separated, forming distinct layers; and he could not imagine that the mere presence of a film of cinder interposed between two layers of iron could increase the toughness of that iron or improve its quality. He quite agreed that the presence of cinder was very often a cause of the brittleness of the iron; but that brittleness he considered was entirely due to the high temperature to which these substances had been exposed when in juxtaposition, by which there was transferred from the cinder to the iron some quality whereby what might have been moderately strong iron was converted into very brittle iron. There was no doubt that Dr. Siemens' former paper in 1868 on puddling had contained a great deal of new and valuable matter; and he believed that

credit was properly due to him for having first pointed out that it was quite possible to puddle iron without any loss at all. The possibility of doing so depended upon the pig iron being brought into contact with reducing substances, such as carbon and silicon, so as to convert the oxide of iron of the fettling into metallic iron; but he dissented from the conclusion that in the rotary gas puddling furnace, or in any furnace in which a moderately high temperature was produced, it was possible to maintain a perfectly neutral flame. And he did not understand how the increased yield obtained in the rotary gas puddling furnace could be due to the presence of a reducing atmosphere in that furnace, whether heated by the regenerative gas system or by the ordinary method.

Mr. C. W. Siemens explained that he had attributed the greater yield of rotary puddling furnaces to the circumstance of the flame being less cutting and less oxidising. A reducing flame he quite agreed was not to be had; but there might be a highly oxidising flame, containing a good deal of free oxygen; and if a flame so charged with oxygen were directed against the iron while in the process of balling, it would cut up and re-oxidise a considerable portion of the iron. If a flame could be had that was perfectly neutral, he should expect to get from 20 cwt. of pig metal put into the puddling furnace about 21 cwt. of puddled bar; but all he should expect practically would be about weight for weight, or rather less, as there was always some oxidation going on under any circumstances. In an ordinary puddling furnace the flame was directed against the iron in the process of boiling in a way that caused a very considerable amount of re-oxidation; whereas in a rotary furnace heated in the ordinary way there was less cutting action, inasmuch as the flame did not strike the iron to the same extent; and in a gas furnace, even though the flame might strike the iron more than in a rotary furnace, there was still less cutting action, simply because the flame was more nearly a neutral flame.

Mr. I. Lowthian Bell denied altogether that there was any such thing as the neutral flame that had been spoken of, for the

reason that, so far as the regenerative gas furnace was concerned, the gas introduced into the body of the furnace was carbonic oxide mixed with hydrocarbons. Now in the ordinary puddling furnace a portion of heat might be obtained by the oxidation to the first stage of the carbon of the fuel, that is, the conversion of this carbon into carbonic oxide; but in the regenerative gas furnace, where the entire heat, so far as the carbon was concerned, was necessarily evolved from combustion of the carbonic oxide into carbonic acid, the gas so produced in the furnace was of itself of a highly oxidising character. To generate heat therefore in such a furnace from something independent of the oxidation of carbonic oxide would involve the difficulty of getting heat without any combustion. The same remarks were applicable to the combustion of hydrogen into the resulting water, for water at a high temperature oxidised iron with great rapidity. Therefore what he asserted was that at the temperature of a puddling furnace there was no such thing as a neutral flame, because it was well known and had been definitely proved that a small quantity of carbonic acid in the flame in such a furnace was capable of oxidising iron. At the same time he agreed that possibly even in a regenerative furnace, and certainly in a rotary furnace, a yield was obtained approaching that laid down by Dr. Siemens; but this he apprehended was entirely due to the circumstance that the operation being independent of limited manual labour was carried on much more rapidly than it could be in the ordinary hand puddling furnaces, and consequently the iron was not exposed so long to the cutting influence of the flame as in puddling by hand.

With regard to the question of phosphoric acid and its reduction to phosphorus—which was one of the most important questions at the present time so far as the manufacture of malleable iron and along with it of steel was concerned—it had been mentioned by Dr. Siemens that in the blast furnace the phosphorus was not got rid of in the pig metal owing to the reducing action of the furnace; but on the other hand it must be borne in mind that in the Bessemer process—one of an intensely oxidising character—the phosphorus was also not got rid of in the metal obtained. In both

these instances he considered the result was independent either of oxidation or of reduction, and was simply a question of temperature: there was one temperature at which phosphorus, previously acidified, combined rapidly with oxide of iron, and there was another temperature at which these conditions were reversed. In the rotary furnace used by Dr. Siemens for his direct process, the reason why there was less phosphorus in the iron obtained was that the furnace was kept at a temperature far below that at which phosphoric acid was deoxidised, and the phosphorus therefore never combined with the iron at all.

Mr. T. R. CRAMPTON mentioned that with Price's double puddling furnace at Woolwich he had found the weight of puddled bars turned out amounted to within 1 per cent. of the total weight of pig iron put into the furnace, on a total make of nearly 1000 tons, the coal consumed being about 8 cwt. per ton of bars. The reason of the good yield of iron appeared to him to be that there was less oxidation in the furnace, that it worked more regularly and rapidly, and the puddling was done in a more homogeneous manner than in the ordinary furnace; the fettling used was of the best description, and the quantity about 6 cwt. per ton of puddled bar. The yield of any puddling furnace no doubt depended greatly upon the quality of the fettling used, and the oxidising action of the flame. A very important principle was involved in the plan of heating Price's puddling furnace: a very narrow fireplace was used; the fresh coal was heated to a certain extent by the waste heat of the fire, and was thereby made into coke, and the gases given off from it passed regularly into the fire chamber; and when it was required to add fresh fuel, the already incandescent material was pushed forward on to the fire, so that it did not cause any check or require extra air to consume it: this was in contradistinction to firing in the ordinary way by putting cold coal in masses on to the hot fire in the furnace. He believed also that a smaller amount of oxygen or atmospheric air was used in that furnace than was ordinarily used in the common furnace. Another reason he considered for the good results obtained with that furnace was that the combustion was

brought nearer to the work to be done than in most other furnaces; and also that a higher temperature was maintained, as the fire never had cold material put on to it. To such an extent was the heat by that means retained in the furnace that with the addition of a little heated air wrought iron was melted in pots without difficulty, and he had recently seen 25 lb. of wrought iron melted in 2 or $2\frac{1}{2}$ hours; for reheating piles from cold to a welding heat the consumption of coal was only 4 cwt. per ton of iron welded. Such results he considered were deserving of attention and consideration, and he did not think that any gas furnace, whether regenerative or not, would produce such good results, where the gas was made at a distance; he did not believe it possible to heat such a mass of material as was required to make the regenerative furnace and consume the gas, without incurring a very serious loss, this being only partially recovered by the regenerators. The great value of the regenerator was that a high temperature could be maintained, as was required in making steel, which had not been generally accomplished in other furnaces; but for lower temperatures, such as required for puddling and welding, he questioned its economy in many respects.

In his own dust-fuel furnace the iron oxidised less in puddling or melting than in any other furnace that he knew of; he had melted down a 6 cwt. puddled ball in 35 minutes, which of course required an exceedingly high temperature, and he had noticed that the ball was of a darker colour than the furnace itself during the time of melting, thus showing that there could be very little cutting action of the flame upon the iron; if there had been any injurious oxidation the ball would have been of a higher temperature and brighter than the flame in the furnace, as all practical men were aware was the case of the ordinary puddle ball when ready to be discharged from the furnace. After a very large experience with the dust-fuel furnace he had produced from 15 to 20 per cent. excess of puddled bloom as compared with the pig iron put in to be puddled; and on reheating the puddled bloom and rolling into bars, even after the double heating and double working he had still had 4 per cent. more iron than was put into the furnace as pig.

This was only due to the fettling, and to the absence of oxidation; the particles of the powdered fuel supplied into the furnace were always in contact with the oxygen of the air, and floating in the furnace ready for combustion without oxidising the iron in the furnace; besides which the combustion took place in immediate contact with the iron under treatment. But in any flame not produced by thoroughly mixing the fuel and the air at the entrance into the furnace, there must always be a large proportion of free oxygen floating in the furnace, ready to oxidise the iron; and even in the best gas furnace, where the gas and air passed in together in large masses, they must float separately to a considerable extent over the furnace, one in the state of carbonic oxide and the other in the state of air or free oxygen, ready to oxidise the iron, before entering into combination; they could not be got together with the same facility as where the powdered fuel was mixed particle and particle with the oxygen before entering the furnace, the air and dust coal traversing the furnace together until consumed. It appeared that in the common puddling furnace it was possible by judicious arrangement to get out the full weight of metal put in, and that with the dust-fuel revolving furnace a considerably greater weight could be got out; he believed a more uniform action could be produced by the use of powdered fuel than by any other system known, for the reason that a minimum of air and capacity of furnace was employed, and the combustion took place in contact with the work.

Mr. E. A. Cowper said that from his own observations he was not able to agree with the statement that there was no approach to a neutral flame in the Siemens gas furnace; because in some of these furnaces, particularly in one at Bolton, which he had examined carefully, instead of the jets of carbonic oxide, as they came out of the puddled iron, burning in visible jets, as in ordinary puddling furnaces, they could not be seen at all. At first he had been rather astonished not to see them, and had some idea that a different action was going on from what was usual; but directly the furnace door was opened and a little atmospheric air allowed to go in, so that

there was oxygen for the jets to burn with, they were at once visible. When there was sufficient oxygen for them to burn, they did burn; but when there was no oxygen for them to burn, or very little, they did not show; that he thought was a pretty good proof that the atmosphere at that time in the furnace was not a very oxidising one.

With regard to the oxidation of sulphur and phosphorus in the Bessemer process, it was well known that it could not be accomplished by a high temperature; neither a low temperature nor a high temperature in the Bessemer converter would burn away sulphur and phosphorus. It had been tried in every way, and with the highest temperatures, but it was impossible, for the reason that a perfect alloy had already been made between the iron and the sulphur and the phosphorus and to a certain extent the silicon; and of these substances the silicon, carbon, and iron were more oxidisable than sulphur and phosphorus; therefore the continuation of the blowing in the converter would have the effect of burning the iron, but not the sulphur and phosphorus.

The sulphur and phosphorus were however got rid of to a large extent in all puddling furnaces. All experience he thought proved that oxide of iron or cinder—good oxide of iron in particular—was much more vulnerable to sulphur and phosphorus than iron itself. If a sufficient quantity of good oxide of iron were present, or of good cinder mixed with the iron, and it were properly puddled so as to let every part of the iron come in contact with the oxide, it would absorb so much of the sulphur and phosphorus as did not escape by the chimney; and when the puddling was finished, the sulphur and phosphorus would be in the oxide and not in the iron. It was well known that in puddling with good cinder or good oxide of iron this result was obtained: it seemed to be almost the only plan for getting the sulphur and phosphorus out of the iron. He had himself tried an experiment in the way of purifying iron of sulphur and phosphorus by oxidising them away, and had under certain conditions taken out fully one half at a low temperature, the iron not seeming to be so vulnerable to these impurities at a low temperature as at a high temperature, that is to say not holding

them with the same tenacity; but even then the iron was somewhat oxidised also.

Mr. JEREMIAH HEAD remarked, in reference to the special subject of the present paper on homogeneous iron, that it was very desirable there should be a clear idea of the meaning of the terms used; and he presumed the term homogeneous meant of like nature throughout. Probably by those who first used this term it was meant to describe what were now called elementary substances—those which were composed of only one substance and not reducible into any others. If this interpretation were taken, then of course only absolutely pure iron could be said to be homogeneous; and as all commercial iron that could be made, whether in the form of cast iron or of wrought iron, was a compound of iron and certain other substances, it could not be strictly called homogeneous. What was wanted by mechanical engineers he presumed was to be able to put iron into such forms as were required for different structures, and that it should be of such a nature as to resist to the very maximum any change of form. The use of any name, such as homogeneous, for merely commercial purposes, was he considered to be deprecated; terms ought to be employed as far as possible in accordance with their original meaning, for, as there were many foreign languages which had words derived from the same source, the scientific language of this country would differ in meaning from those of other countries, if the original meaning of the terms employed were departed from.

In the present paper the question had been raised as to whether iron which broke with a fine grain and steely fracture was not better than iron which broke with a fibrous fracture. On this point he was inclined to agree with the view taken in the paper; for it seemed to him pretty clear that, with a fracture which was fine and straight across, the maximum number of atoms must have been in contact with one another and they must have all pretty well acted together; while in the case of iron that with a direct pull broke in a fibrous way, it seemed clear that some had been severed before the rest, and therefore they had not all acted together. Whether the

term fibrous was strictly applicable to wrought iron at all appeared to him questionable; the original meaning of fibrous no doubt referred to the structure which was seen in a rope or in wood, which had suggested the employment of the term fibre in connection with wrought iron. But in severing a rope sideways, it was clear that it would part company not by any rupture of the fibres, but by the pulling of them apart; and if a piece of wood were broken across the grain, it was clear that the break was not in the main fibres of the wood, but in the substance which cemented or bound them together. Then again it was inconceivable that by any mechanical action upon a rope or upon wood could the strength be given to it sideways which it had endways; but it was quite otherwise with malleable iron, in which the fibre seemed to be produced mainly by the work done upon it when hot, generally in the way of rolling. It was well known to iron manufacturers that the strength of bars or plates was greater in the direction of the rolling than it was across the rolling, in the proportion of something like 22 to 18 in plates. But it was also well known how much this proportion varied with the shape of the plate which was rolled; a long narrow plate would be stronger than the average in the direction of the fibre, and weaker than the average across the fibre, whereas a square plate, which had been rolled pretty equally both ways, gave less than the average in the direction of the fibre, and more than the average across the fibre. The fact that two true surface plates would stick together had been long known, but it had generally been attributed to the atmospheric pressure, owing to the exclusion of air from between the plates; but it had been shown by Prof. Tyndall that these plates when put together under a vacuum still stuck together, and that the lower plate would support a weight greater than was due to the pressure of the atmosphere. This had been accounted for by saying that the particles of the two plates were brought within the influence of the attraction of cohesion. Now the attraction of cohesion was probably what was come to in determining the ultimate stress which iron or any other material would bear, and what was wanted to be accomplished in the manufacture of iron was to get the atoms of iron into as close contact as possible. This meant the

exclusion of all foreign substances, in which the coefficient of cohesion might be less than that of one particle of iron with another particle of iron. When it was considered that in an ordinary horse-shoe magnet the keeper or armature offered great resistance to its removal while in contact with the poles of the magnet, but at a little distance offered far less, this showed the extreme importance of getting the particles of iron as close together as possible, and of having in the cross section of any piece of iron that was broken the maximum area of absolute or close contact. If this were so, it was clear that a fine-grained fracture ought to give greater resistance than a coarse-grained one: just as, if a cross section were taken through the centre of a sack of sand, there would be a greater surface of contact than in a cross section taken through the centre of a sack of paving stones. Applying this principle to the fact that plates offered a greater resistance in the direction of the grain than across, he supposed the reason must be because in the process of rolling the particles were forced forward, being heaped up, as it were, one against the other, and then squeezed down with great force, so that in that direction they were put into closer and more absolute contact than they were across the direction of rolling: just as, if the floor of a room were spread over with sand and a series of brooms were set to sweep it up in the direction of the length of the room, it was clear that the sand would be heaped up in front of the brooms, whereas sideways the different heaps might have very little connection. The process of rolling a plate or bar of iron seemed to him to be similar, only that the particles, instead of being merely heaped up like sand, were forced forward into very much closer contact, whereas there was not the same force exerted to bring them into side contact. This idea seemed to be recognised in the making of plates at those works at which rolling mills were being put down with very long rolls, as was being done at Low Moor and at some others of the South Yorkshire works, where rolls of 11 or 12 ft. length were being put down, the idea being, in rolling large circular plates, to put them through first one way and then at right angles, in order to get equal toughness for flanging all round, the length of the rolls being sufficient for the maximum dimension of the plate.

Mr. KIRK observed, in regard to the reduction in the strength of iron by the presence of cinder interposed in it, that, though he could not say exactly how it was that the strength of the iron was thereby reduced to such an extent as was found to be the case, he thought Mr. Head's explanation of the phenomena was in the main correct. So far as cinder existed in iron it must reduce the strength, because it was no doubt in a powdery condition, and therefore altogether lacking cohesion, and must at least reduce the strength of the iron to the extent of its percentage. But in actual practice it was found that when a large quantity of cinder was present there was also cold-shortness; and in the specimens now exhibited, broken from a $\frac{3}{4}$ in. round bar containing a large percentage of cinder, warm-shortness was met with in conjunction with fractures of very peculiar colours, the short pieces shown having been easily broken off with the blow of a hand hammer at the temperature at which wood began to char. The working that had been named of the double puddling furnace at Woolwich, with 6 cwt. of fettling per ton of puddled ball and only 1 per cent. waste, seemed very remarkable, and the performances of the rotary dust-fuel furnace still more so. It appeared to him however, from such chemical calculations as he had been able to make, that it was not possible to obtain an increase of 15 to 20 per cent. of metallic iron over and above the weight of pig charged; there must have been some cinder present in the puddled bloom to help up the weight. When superintending some experiments at the Woolwich coal-dust furnace in 1873, he had found on one occasion a very large increase of yield, which he considered due to the presence of cinder, because some of the iron had got too cold to be properly hammered; and an experiment had been made by Mr. Price to find out the quantity of cinder there was in ordinary puddled balls, by weighing eight balls, first on coming out of the furnace, and then again after they had been hammered into blooms, when the loss of weight in hammering was found to be as much as $20\frac{1}{2}$ per cent., on account of the large quantity of cinder that was driven out. It was probable, from reasons given in the paper, that there was considerably more cinder in puddle balls from rotary furnaces; and in some other experiments

which had mystified ironmakers a good deal he was of opinion that there had also been a much larger percentage of cinder than had been credited.

The President remarked that they were much indebted to Mr. Kirk for his paper, and moved a vote of thanks to him for the paper, which was passed.

The following paper was then read :—

ON ROOTS' MINE VENTILATOR, AND OTHER APPLICATIONS OF ROOTS' BLOWER.

BY MR. E. HAMER CARBUTT, OF BRADFORD.

The Roots' Blower is a rotary air-compressing machine, as distinguished from a fan which throws the air off by centrifugal action. In principle it is analogous to a blowing cylinder, with this difference, that the air is expelled constantly in one direction and in four distinct volumes at each revolution of the blower; but with a blowing cylinder the direction of the current of air is altered at each end of the stroke. The position of the blower is therefore between the fan running at a high velocity, delivering a large volume of air at a low pressure, and the blowing cylinder with a piston working at a slow speed, expelling a small volume of air at a high pressure.

For a long time previous to the introduction of Roots' blower into this country, it had been extensively used in America; blowers of a capacity of 100,000 cub. ft. per min. had been constructed there, and one of this capacity was employed for working a pneumatic railway under Broadway, New York. For smelting and similar purposes the blower had earned a reputation, and was well known amongst engineers and ironfounders in that country. In 1867 it was shown at the Paris Exhibition, and attracted considerable attention and critical examination at the hands of practical men. The writer was strongly advised to introduce it into this country by the late Mr. Zerah Colburn, who was familiar with its working in America, and emphatically declared that it was superior to any fan blowing machine in operation, and in his opinion it would occupy the first place amongst machines of its class. How far this prediction has been fulfilled is sufficiently shown by the experience of the last ten years, during which period a large number of blowers have been supplied for foundries, smiths' shops, portable forges, and other purposes.

It will readily suggest itself that the application of the blower is extensive; many chemical processes and mechanical operations require a strong current of air at pressures up to 3 lb. per sq. in. Roots' blower can under ordinary conditions compete with blowing cylinders up to that pressure, especially in volume of air delivered, percentage of useful effect, and first cost. Hence it recommends itself to the ironfounder for melting iron in the cupola; to the metal smelter for lead, copper, and silver smelting; to the chemical manufacturer for moving hot or cold gas from one chamber to another in the manufacture of sulphates and other chemicals; to engineers and blacksmiths for smiths' fires and steam-boiler furnaces; to the iron and steel maker for puddling furnaces and spiegel cupolas; to the architect for ventilating buildings and testing sanitary drains; to the brewer for drying casks and reducing the temperature of cooling rooms, and also for cleaning malt and grain; to the manufacturer for drying wool and other fibrous materials, and for engraving upon glass; for feeding printing machines, for pneumatic despatch tubes, and for other processes too numerous to mention. For pneumatic tubes, the application of the blower has been very successful in America; and a noted firm in this country in connection with pneumatic tubes are fitting up the blowers at the post offices for the transmission of telegraph messages from the receiving counter to the instrument room above, and at other government offices for moving small parcels and messages from one room to another. As an exhausting machine, the blower is also applied with advantage for gas exhausting and for the ventilation of mines.

The leading feature of Roots' blower consists of two duplicate rotary pistons, fixed upon separate shafts and working in a casing, which is provided with inlet and outlet openings either at the top and bottom, or at the sides, according to the position in which the machine is arranged. The rotary pistons in revolving are maintained in their proper relative positions by gearing on the shafts, and they revolve closely together, but not in actual contact with each other or with the casing; hence the absence of internal friction. The action of the pistons is illustrated by the two working models exhibited, showing a section of the pistons and casing. For different purposes

the pistons are formed of two distinct types, which will admit of having their proportions changed within certain limits. With the proportions shown in the diagram Fig. 29, Plate 14, it will be noticed that there is more space for the air and less space occupied by the pistons AA than with the proportions shown in Fig. 30. With a casing of definite size therefore the capacity or volume of air forced forward will be considerably more with rotary pistons of the proportion in Fig. 29; and this is the proportion adopted in Roots' blowers for forcing or exhausting air. The type and proportions of the rotary pistons shown in Fig. 30 are similar to those used in Jones' gas exhauster; but for Roots' gas exhauster that type of rotary piston has been discarded as unsuitable, because without considerable space or leakage between the pistons there is not sufficient room for the gas tar and other sediment deposited from the gas in passing through the machine. For gas exhausting therefore the type of rotary piston shown in Fig. 31 is used; and this form still retains the elements of close fitting to prevent the gas from escaping backwards, and allows plenty of space T T to receive the gas tar so as not to interfere with the running of the machine. The rotary pistons of this type do not require to be so correctly maintained in their proper relative positions, and a small movement of either of them towards or away from the other will not cause them to knock together or come in contact. The rotary pistons in Fig. 31 consist of the centre cylinder C and the outer extremities A A; and these are portions of circles, and are easily and accurately produced in the lathe and shaping machine. The extremities A A are less than quarter circles; this gives considerable clearance between the points X X, and allows the gas between the pistons in the spaces T T to get away freely.

Roots' Ventilator for Mines is shown in Figs. 1 to 8, Plates 2 to 5; Fig. 4 is a cross section of the ventilator, and Figs. 5 and 6 a longitudinal section and a plan of the ventilator and engines; Figs. 7 and 8 are longitudinal and cross sections of the ventilator to a larger scale.

This Ventilator has been fixed at the Chilton Colliery, near Ferryhill, belonging to the South Durham Coal Co., and was started at the beginning of this year, and has been in constant work up to the present time. It consists of the two rotary pistons A A, which are each 25 ft. diameter and 13 ft. wide, and are built up upon steel shafts B. Upon each of the shafts are keyed five cast-iron disc-plates C C, having at their circumference flanges which are all turned up exactly of the same diameter. In each disc-plate there are three wrought-iron bars D fixed on each side of the centre, and reaching to the outside of the rotary piston; planed recesses are provided in the disc-plates to receive the bars, which are also secured to the disc-plates by bolts turned to fit. The outer ends of the bars are widened, and marked off and slotted to the radius of the outer circle. Angle irons bent to the radius of the outer circle are riveted to the extremities of the bars, and are covered with $\frac{1}{4}$ in. sheet-iron plates; the centre circles are also covered with $\frac{1}{4}$ in. sheet-iron plates riveted on the turned flanges of the disc-plates C C. The sides F F of the pistons are covered with wood, and the ends with sheet iron. These rotary pistons revolve in bearings fixed upon deep cast-iron girders G G, which form the framework of the ventilator pit, and are connected together at each end of the ventilator by cross girders. The girders G G and the cast-iron side plates J J are planed on their inside surfaces, and the stonework of the ventilator pit is dressed off level with the planed girders.

The engines to drive the ventilator are a pair of 28 in. cylinders with 4 ft. stroke, and provided with adjustable cut-off valves. The engines are placed at right angles to the ventilator, and are connected to it with bevil wheels 9 ft. $2\frac{3}{4}$ in. diameter, two bevil wheels being fixed upon the crank shaft, each gearing into a bevil wheel K keyed upon the end of the ventilator shafts. The engine beds are carried down and fixed upon a stay girder L, which in turn is securely keyed and bolted to the main girder G.

The main girders are fixed 13 ft. $0\frac{1}{4}$ in. apart, therefore the clearance between the rotary pistons of 13 ft. width and the sides of the ventilator pit is only $\frac{1}{8}$ in. on each side. At each end of the ventilator pit and at the bottom on each side of the inlet from the

upcast shaft, adjustable packing blocks of timber I I are fixed upon hinged iron frames, and can be adjusted with screws and nuts; these blocks are set up quite close to the periphery of the rotary pistons within $\frac{1}{8}$ in. The clearance between the periphery of one of the rotary pistons and the centre circle of the other is the same, and thus in any part of the ventilator the clearance for loss by returning of the air is not more than $\frac{1}{8}$ in.; this will help to account for the measured quantities of air in Table II (appended) corresponding so closely with the calculated capacity or displacement, which is 5,800 cub. ft. per rev. Between the packing blocks I I the ventilator pit is dug out and lined up with cement; but there is considerable space between the layer of cement and the outside circle of the rotary pistons, and dependence is placed only upon the packing blocks I I to maintain the tightness of the pistons with the ends of the ventilator pit.

The rotary pistons are equally balanced, and the friction diagram, Fig. 14, Plate 7, in experiment No. 1, Table III, shows that 3·10 Ind. H. P. maintained the ventilator and engine running at a constant speed of 3 rev. per min.; this proves that the balancing has had attention, and that not much power is lost in the friction of the moving parts. Chilton Colliery is a new pit raising 800 tons of coal per day, and the present requirements in the way of ventilation are amply met by running the ventilator at 15 rev. per min., giving a calculated displacement of 87,000 cub. ft. of air per min. At this speed better results would be obtained by using only one cylinder, and letting the other engine stand, as will be done in the case of repairs; the two engines are only intended to be used when the ventilator is working up to its full maximum quantity of 200,000 cub. ft. of air per min. The arrangement of the engine house and ventilator building is shown in Figs. 4 and 5, Plate 3; the discharged air escapes through perforated openings in the roof, and owing to the very large area of outlet from the ventilator—the top of the ventilator casing being left entirely open—the air that is being exhausted from the pit must necessarily be delivered into the atmosphere at a lower velocity than is usual with other ventilating machines.

The tabulated statements appended, Tables I, II, and III, contain the results of experiments made at two trials of this ventilator. In the anemometer measurements Biram's anemometer was employed, and the readings in Table I are corrected by means of a table supplied with the instrument, which was tested for the purpose of these trials. In experiments Nos. 4, 5, 8, and 10, the anemometer and water gauge measurements were taken simultaneously with indicator diagrams from the engine cylinders; the indicator diagrams are shown in Plates 6 and 7. The areas and position of the upcast shaft and tunnel are shown in Figs. 1 to 3, Plate 2; the sectional area of the tunnel is only 112 sq. ft. at the point M where the anemometer measurements were taken, which is much too small. On reference to experiment 16, Table I, it is seen that only one reading of 2,300 ft. per min. could be taken, in division No. 6; and on comparing the proportions of the velocities in each division it will be noticed that in the top divisions, Nos. 1, 2, 3, and 4, Fig. 2, the air would have a velocity of nearly 3,000 ft. per min.; this very high velocity means corresponding loss of power from the friction of the air, when it is remembered that the power required to overcome the friction of the air in any given area increases in proportion with the square of that velocity.

The useful effect obtained with this ventilator is shown in Table III; and for the purpose of comparison, the following particulars are reproduced from the paper on mechanical ventilators for mines read by Mr. Daniel at the meeting of the Institution Nov. 1875 (page 321), the lowest as well as the highest results being given in the case of the Roots' and the Cooke's ventilators, and the highest alone in the case of the others.

		Ventilator. Diam. Width. Ft. Ft.	Air per min. Cub. Ft.	Water Gauge. In.	Revs. per min.	**Useful Effect.** Per cent.
Roots	Chilton	25 × 13	74,928	4·00	13	**76·85**
			101,696	5·00	18	**64·19**
			67,312	2·75	12	**56·30**
			118,272	4·12	21	**51·40**
Cooke	Lofthouse	22 × 11½	101,308	1·12	26	**64·00**
			96,757	1·00	26	**59·16**
	Upleatham	22 × 11½	88,900	3·25	27	**61·18**
			120,816	1·56	29	**58·50**
Waddle	Aberaman	36 × 1½	126,504	1·60	44	**47·10**
Rammell	Cannock Chase	32 × ½	45,280	2·10	55	**41·02**
Leeds Fan	Morley Main	40 × 10	141,534	1·80	44	**37·92**
Guibal	Farnley Wood	21 × 7	38,900	0·90	53	**50·41**
	Liverton	36 × 12	121,688	2·55	51	**48·85**
	Hilda	50 × 12	116,792	2·63	36	**45·81**
	Skelton	30 × 10	52,544	0·50	28	**45·64**
	Craggs Hall	30 × 10	56,072	1·40	43	**40·66**

This comparison shows that the range of Roots' blower when employed as an exhauster is in advance of any of the previous mechanical ventilators; and in the writer's opinion this would be a decided advantage in the case of an explosion. When the air doors become disarranged, the ventilation of the mine is interfered with at the moment when it would be of the greatest service, and this owing to the limited power of fan ventilators, which can only be depended upon up to about 3 in. water gauge; but in a case of emergency with a Roots' ventilator similar to the one described, the machine could be instantly driven at its maximum power, and would speedily clear the workings of the choke-damp or after-damp. Since explosions cannot always be prevented, it is of importance that the deadly gases should be drawn out in the shortest possible space of time and replaced with pure air; and from present experience this ventilator appears to be admirably fitted to suit these requirements.

Special Blowers for pressures up to 3 lb. per sq. in. are shown in Figs. 15 and 16, Plate 8. Blowers of this description have been constructed to supply from 100 to 10,000 cub. ft. of air per min. The rotary pistons A are made of cast iron, turned up true on their outside

periphery, and the centre circle of the piston is shaped. The pistons are keyed upon Bessemer steel shafts B, and run in gunmetal bushes firmly fixed in the end plates of the casing H, which is formed with portions of a cast-iron cylinder with strips I; these are bored the same diameter as the outside of the rotary pistons, before the cylinder is split. The end plates K are planed on the inside, and a top plate is inserted containing the outlet opening. The end plates, sides, and top of the casing are bolted together and to a bedplate. The rotary pistons are kept in their proper relative positions by spur wheels N. These machines have been used for forcing air into oil tanks through a depth of 6 ft. of liquid.

A modification of this description of Blower is shown in Figs. 17 to 19, Plate 9, attached to a portable forge, and a working portable forge fitted with the blower is shown; these forges are exclusively used in out-door work by smiths and boiler makers for repairs, and by country blacksmiths instead of the old-fashioned and clumsy bellows. The three small blowers exhibited, fitted with hand wheels, are constructed in the same manner as the special blowers illustrated in Figs. 15 and 16, and are the sizes in use for transmitting telegraph messages from one room to another in the post office and other public offices.

Ordinary Blowers for cupolas and smiths' fires are shown in Figs. 20 and 21, Plate 10, and also by the full-size cross sectional working model exhibited of a No. 5 blower. These have the rotary pistons covered with wood lags, by which construction the pistons can be made lighter than cast-iron pistons, and thus take less power, run more quietly, and at twice the speed of the iron pistons. It will be noticed in the sectional model that the rotary pistons work very nearly in contact; the thickness of a sheet of paper is the only clearance that is allowed, and in order still further to reduce the clearance a frictionless composition is applied with a brush evenly over the surface of the hollows of the rotary pistons until every portion of the pistons is shown to be in contact. This composition is of the consistency of ordinary paint, and also answers the purpose of preserving the wood. The wood used is the finest selected deal, free from knots, thoroughly seasoned and dried for three years.

The lags are held upon malleable-cast crossheads with bolts, which for security have the bolt ends riveted over the nuts. At the joints of the wood lags is inserted an iron tongue, which runs the whole length of the joints. The end plates K are planed, and are provided with bosses, which are bored and fitted with hard gunmetal bushes, forming the bearings for the steel shafts B; these gunmetal bearings are long, with considerable area of wearing surface, and can be easily replaced when worn out. The side plates of the casing are half cylinders, cast separately, planed on the flanges, bolted to form a circle, and then bored out as true as a steam-engine cylinder; the side plates and end plates are connected together with fitted bolts. The outlet branch is fixed in most cases at the bottom, and a perforated box cover is fixed at the top to admit the air and to prevent anything else entering the machine. At each end, outside the casing of the blower, is fixed a pair of accurately pitched spur wheels for gearing the two pistons together, which are covered in with iron boxes. Upon the iron box is fixed a cover plate provided with gunmetal bushed bearings for the shafts B, and outside of these covers are fixed the driving pulleys on one end of one shaft and on the opposite end of the other shaft, a crossed and open belt from a countershaft being used for driving; and outside the driving pulleys are fixed additional bearings to take the pull of the driving belts. All portions of these machines are made in duplicate, and the wood-covered rotary pistons are correctly shaped to templates by a wood-planing machine; the original method of hand-shaping the revolvers, which was at first tried, could not be depended upon to produce the rotary pistons quickly and with sufficient accuracy.

In Figs. 22 and 23, Plate 11, is shown an arrangement of engine connected to a blower, which has been specially designed for driving two shafts in opposite directions. It consists of a standard O with the two crosshead guides and bearings for cranks in one casting. The cylinder is fixed upon the top of the standard, and is provided with steam and exhaust ports of sufficient area to allow of quick speeds. The piston is made deep, and in the crosshead P are two gudgeon pins of hardened steel. From

these two pins are suspended two connecting-rods, working direct upon steel crank-pins fixed into cast-iron crank disc-plates which are keyed upon the rotary-piston shafts B B. The two connecting-rods here counterbalance each other; and the crosshead gudgeon-pins being at equal distances from the centre of the piston rod, there is the minimum strain upon the piston rod and slight wear upon the crosshead guides. Upon each of the blower shafts B B is keyed a balanced flywheel C, and from one shaft the valve of the engine is worked direct with an eccentric R. The engine and blower are mounted upon a cast-iron bedplate; and the whole forms a compact arrangement, dispensing with driving belts and counter shafting, and the speed of the engine and blower can be regulated by the stop-valve S in proportion to the work to be done.

A Chemical Blower and Exhauster is shown in Figs. 24 to 26, Plate 12, specially constructed for Hargreaves' process for the manufacture of sulphates, where the gas to be moved is heated to a temperature of 300° Fahr. The rotary pistons A are of cast iron, and shaped to the correct form. To retain the heat, the casing of the blower is covered with the composition used for covering steam boilers. If the rubbing parts of the machine were allowed to attain the temperature of the gas passing through it, a very rapid wear would take place; but this is provided for by making the shafts revolve in gunmetal bushes fixed in hollow brackets G G, through which a current of cold water is kept running slowly, so as to keep down the temperature of the brasses; from the position of the inlet and outlet holes in the brackets the water has little cooling effect on the casing of the blower. Stuffing-boxes are not required in this case, as the small amount of air that leaks through is of little importance, and there is no tendency for the gases to leak outwards unless great resistance is placed upon the exit side of the blower. The iron pistons and casing of the blower are not injuriously acted upon by the gases, so long as the temperature is sufficiently high to retain them in a gaseous state; and the blower receives no more injury than it would by moving the same volume of atmospheric air.

The Gas Exhauster is shown in Figs. 27 and 28, Plate 13. The casing is made upright, with the inlet opening at one side and the outlet at the opposite side. The special features in this machine are that the rotary pistons A A are made of cast iron tooled over, and of a shape that allows space for the gas tar to collect without disarranging the working. The shafts B B work in adjustable bearings G G outside the end plates of the casing, with a space between these bearings and the end plates, which prevents tar from working into the bearings and the spur gearing. The packing strips I I for securing the close fitting of the rotary pistons A A are made adjustable from the outside of the casing of the machine, as shown in Fig. 27. The capacity of the exhauster here shown is 30 cub. ft., and it is driven at 60 rev. per min. These gas exhausters are also fitted up with an ordinary vertical pillar engine, geared direct upon one of the exhauster shafts, the engine and exhauster being fixed to one bedplate. They have not been used to any great extent in this country; but in America they are being extensively applied, in preference to exhausters that have sliding or rubbing surfaces exposed to the tar.

It will be observed that cog-wheels are employed in all the modifications of blowers described, and that these wheels play the important part of maintaining the rotary pistons in their proper relative positions in revolving; and so long as the pistons can be thus maintained there will be an absence of internal rubbing, and the friction of the machine is confined to the shaft bearings and the cog-wheels. Hence the importance of providing large wearing surfaces that can be easily renewed, and of having accurately pitched wheels; great attention has been bestowed upon these parts, and the blowers as now made are noiseless compared with those made at an earlier date.

In fitting up blowers either for forcing or for exhausting, care has to be taken that the air-conducting pipes and shut-off valves are perfectly tight; and an escape valve should be fixed upon the air pipes to relieve the blower from too great an increase of pressure of air caused by the closing of the shut-off valves while the machine

is in operation. From experience the writer considers that a pressure of air equal to a 12 in. column of water is sufficient for smiths' fires; and the result of experiments is that Roots' blower at this pressure utilises from 50 to 70 per cent. of the power expended in driving it. For melting iron in the cupola, a pressure of air equal to a 20 in. column of water is requisite to secure economical results; and at this pressure the blower utilises from 60 to 80 per cent. of the power expended.

The maximum speed of these blowers with wood-covered rotary pistons is from 300 to 400 rev. per min., and with iron rotary pistons from 100 to 250 rev. per min.; and it will be noted that these speeds are moderate when compared with the speeds of fans to produce the same pressures of air.

This blower has also been applied to move a large volume of air at slow velocity by taking advantage of the injector principle, as follows. The blower forces a jet of air at quick velocity into a large annular funnel-shaped opening; the consequence is that the current of air from the blower draws along with it at a slow velocity from four to eight times the volume of air that is delivered by the jet from the blower; and this arrangement has been successfully carried out for drying machines and also for the ventilation of buildings.

TABLE I.

Roots' Mine Ventilator at Chilton Colliery, Ferryhill. Velocities of Air in different portions of Area of Tunnel.

No. of Experiment	3	4	5	7	8	10	12	16
Rev. p. min. of Ventilator	**10·5**	**12**	**13**	**17**	**18**	**21**	**23**	**37**
Position of Anemometer.	Velocity of Air.	Velocity of Air.	Velocity of Air.	Velocity of Air.	Velocity of Air.	Velocity of Air.	Velocity of Air.	Velocity of Air.
See Fig. 2, Plate 2.	Ft. per min.	Ft. per min.	Ft. per min.	Ft. per min.	Ft. per min.	Ft. per min.	Ft. per min.	Ft. per min.
1	720	810	920	1125	1240	1350	1480	...
2	695	725	805	1080	1050	1285	1315	...
3	580	590	715	930	985	1100	1250	...
4	570	690	635	855	1035	1150	1190	...
5	560	610	750	1000	900	1110	1275	...
6	565	625	700	930	935	1120	1210	2300*
7	610	720	710	960	1050	1240	1270	...
8	220	230	255	335	400	475	550	...
9	360	430	400	530	615	760	840	...
10	435	580	800	1075	870	975	1175	...
Mean	**531**	**601**	**669**	**882**	**908**	**1056**	**1155**	**2185**

Velocity of Air measured by Biram's Anemometer. Sectional Area of Tunnel from upcast shaft to ventilator = 112 sq. ft.

* In No. 16 experiment, at 37 rev. per min., this was the only measurement that could be obtained; the area of the tunnel being too contracted for so large a quantity of air, men could not remain in the tunnel many minutes, owing to the high velocity of the air current, and to a large quantity of water being drawn in with the air. The difference in the other experiments between the mean velocity of the air and its velocity in the centre of No. 6 division of the tunnel area averages 5 per cent.; and this proportion being applied to No. 16 experiment gives 2185 ft. per min. as the mean velocity.

TABLE II.

Roots' Mine Ventilator at Chilton Colliery, Ferryhill.

Measured and Theoretical Deliveries of Air at different velocities.

No. of Experiment		3	4	5	7	8	10	12	16
Date of Experiment	1877	Mar. 17	Mar. 17	Mar. 17	Mar. 17	Feb. 3	Feb. 3	Mar. 17	Feb. 3
Revolutions of Ventilator . . . . R	per min.	**10·5**	**12**	**13**	**17**	**18**	**21**	**23**	**37**
Velocity of Air in Tunnel (Table I) . V	ft. per min.	531	601	669	882	908	1056	1155	2185
Delivery of Air: Theoretical* R × 5,800 = T	cub. ft. p. min.	60,900	69,600	75,400	98,600	104,400	121,800	133,400	214,600
Delivery of Air: Measured† . V × 112 = M	cub. ft. p. min.	59,472	67,312	74.928	98,784	101,696	118,272	129,360	244,720
Ratio . . . . $\frac{M}{T} \times 100$	per cent.	97·65	96·71	99·37	100·18	97·41	97·10	96·97	114·04
Leakage	per cent.	2·35	3·29	0·63	...	2·59	2·90	3·03	...

* The Theoretical Delivery is the capacity of the ventilator (5,800 cub. ft.) × rev. per min.

† The Measured Delivery is the velocity in the tunnel × 112 sq. ft. sectional area of tunnel.

In Nos. 4, 5, 8, 10, the Air Measurements in Table I were taken simultaneously with those of Ind. H. P. given in Table III.

The experiments Nos. 3, 7, 12, 16, are not carried out in Table III, the whole of the data not being obtained in those cases.

TABLE III.

Roots' Mine Ventilator at Chilton Colliery, Ferryhill.

Useful Effect of Ventilator and Engine.

Engine with two cylinders, 28 in. diam. and 4 ft. stroke.

No. of Experiment		1	2	4	5	6	8	9	10	11	13	14	15
Date of Experiment	1877	Mar.16	Mar.16	Mar.17	Mar.17	Feb. 3	Feb. 3	Feb. 3	Feb. 3	Feb. 3	Mar. 17	Mar. 17	Mar. 17
Revs. of Ventilator and Engine . . R	per min.	**3**	**8**	**12**	**13**	**14**	**18**	**20**	**21**	**22**	**28**	**30**	**32**
Steam Pressure in pipes	lb. per in.	33	35	37	40	45	45	46	49	48	45	52	60
Point of Cut-off in engine	per cent.	30	30	30	30	30	30	40	30	40	80	80	80
Delivery of Air: Theoretical . . $R \times 5{,}800 = T$	cub.ft. p.min.	...	46,400	69,600	75,400	81,200	104,400	116,000	121,800	127,600	162,400	174,000	185,600
Delivery of Air: Measured (Table II) . . M	cub.ft. p.min.	...	...	67,312	74,928	...	101,696	...	118,272	...	...	...	...
Water Gauge . . . . W	inches	**0·00**	**1·25**	**2·75**	**4·00**	**4·00**	**5·00**	**6·50**	**4·12**	**5·87**	**6·00**	**7·00**	**7·75**
Mean effective steam pressure: right cyl.	lb. per in.	3·47	6·65	14·47	...	17·65	22·80	29·80	23·95	30·95	...	46·40	51·15
Mean effective steam pressure: left cyl. .	lb. per in.	...	...	...	15·85	17·25	23·75	29·30	23·70	31·25	39·85	...	...
Ind. H.P. from diagrams: right cyl.	H.P.	...	...	...	...	73·68	122·30	177·70	149·90	203·00	...	...	...
Ind. H.P. from diagrams: left cyl. .	H.P.	...	...	...	...	72·01	127·40	174·70	148·40	205·00	...	...	...
Ind. H.P. from diagrams: Mean . . I	H.P.	3·10	15·50	51·79	61·44	72·84	124·85	176·20	149·15	204·00	332·70	415·00	488·00
Effective H.P.: Theoretical $\frac{T \times W \times 5{\cdot}2}{33{,}000} = Et$	H.P.	Friction diagrams	9·14	30·16	47·52	51·18	82·25	118·81	79·17	118·12	153·54	191·92	226·65
Effective H.P.: Measured $\frac{M \times W \times 5{\cdot}2}{33{,}000} = Em$	H.P.		...	29·16	47·22	...	80·12	...	76·88	...	...	...	...
Useful Effect Vent.r and Eng.: Theoretical $\frac{Et}{I} \times 100$	per cent.		58·96	58·23	77·34	70·26	65·90	67·42	53·09	57·90	46·14	46·24	46·24
Useful Effect Vent.r and Eng.: Measured $\frac{Em}{I} \times 100$	per cent.		...	**56·30**	**76·85**	...	**64·19**	...	**51·40**	...	...	...	...

Working models and specimens of the several machines were shown at work, with gauges indicating the pressures obtained.

Mr. C. Cochrane observed that, in addition to the applications mentioned in the paper, Roots' blower had also been applied in practice to the sand-blast process, for projecting a jet of sand at a high velocity against glass in order to cut out ornamental patterns upon its surface; and the same could be done even in such hard substances as granite by the use of this blower.

Allusion had been made in the paper to the air doors getting disarranged in mines in the event of an explosion, and it appeared to be supposed that the Roots' ventilator would be more effective than others under those circumstances; but he was afraid cognisance had not been taken of the fact that, when the air doors in a mine were disarranged, the ventilation was not merely interfered with for the moment, but the mine had to be entered and the doors replaced before ventilation could be restored, because it was presumable that the doors were blown away in the working parts by the explosion, so that direct access from the downcast to the upcast shaft would be left for the air, which would at once take the shortest course. In this connection therefore he feared no advantage could be urged over other ventilators in favour of the one now described.

Mr. D. Adamson mentioned that he remembered this system of revolving pistons being invented about forty years ago by Mr. Robinson Jackson, then a fellow apprentice of his own, by whom it was designed as a rotary engine and pump; but he presumed all the credit was due to Messrs. Roots for having introduced it as a blower, and he did not know that the original inventor had had any intention to make it act as a ventilator. The paper just read he considered a very excellent one, as the blower dealt with large quantities of air forced at slow velocities, in contradistinction to the ordinary fan, which, when operating with large quantities of air must always throw it off at the circumference at a very high velocity. The useful effect of any ventilating machine must be somewhat in proportion to the quantity of air discharged or exhausted at the least possible speed: the

ordinary fan threw the air off at a high speed, whereas this ventilator operated more like a reciprocating piston, and did not give the air a higher velocity than was due to the slow movement of the machine. Whether the increased weight to be put in motion might have a counteracting effect on the economy of this machine as a ventilator and as a blower, he was not prepared to say. In the case of a fan, throwing the air off at a higher velocity, there was less weight to be put into motion in the machine itself; and the greater weight of the ventilator now described might he thought prevent its being so economical as was suggested by the tables of experiments given in the paper.

The friction of two surfaces, if they came into contact one at a much higher speed than the other, must always be an element of mechanical destruction; and as far as his own experience went, or information received from others, he thought the revolving pistons of the blowers did not unfrequently break from want of balance, or from their two surfaces striking each other while moving one at a higher speed than the other. But the information he had received might have been, as suggested in the paper, from the results of working with some of the earlier blowers that were not so well balanced as the present ones. The efficiency of the revolving pistons when made of wood had been spoken of as much greater than that of cast-iron revolvers, and it would appear that the only reason was the difference in the weight of the two constructions; but he could not help thinking there must be some mistake on that point. If the cast-iron revolvers were truly shaped and perfectly balanced after being shaped, they must be more enduring he considered than if made of wood, and much less liable to get out of order through variableness of temperature or owing to different states of moisture of the atmosphere or from the gases passing through the machine; and a blower constructed with cast-iron revolvers so made would in his opinion be capable of running at a higher velocity and with much greater durability than one with revolvers made of wood.

Mr. JEREMIAH HEAD said one of the blowers of No. 5 size, with engine combined on the same bedplate (as in Plate 11), had been put

down at his own works about three months ago, and had been in constant work since then. On the whole it had worked very well, running from 250 to 300 rev. per min., which was the highest speed it had been driven at; it maintained at that speed a column of about 14 in. of water, and was employed for blowing a cupola having four tuyeres of about 5 in. diameter, melting down as a maximum about 4 tons per hour. At the speed of 300 rev. per min. it had been found necessary to keep a little water running upon the bearings of the two blower shafts, in order to keep them cool. The machine worked with a hum, but did not make much noise—not more perhaps than could reasonably be expected. He had also been afraid of wood revolvers, and had therefore stipulated that they should be of cast iron, having understood that it was absolutely necessary that the wood revolvers should only be used where the situation was pretty dry, otherwise the whole machine got out of order by the swelling of the wood. He had also at work a blowing fan, 4 ft. diameter, constructed on the Guibal principle, which also supplied four tuyeres of 5 in. diameter, and at 1100 rev. per min.—the speed at which it was driven—maintained a column of 18 in. of water; and the hum or noise made by the fan was about the same as that made by the Roots' blower. In the case of the combined engine and blower on the same bedplate there was of course the advantage that the whole machine was complete and self-contained, and could be put down anywhere, requiring simply a steam pipe to be brought to it. The duplex action for driving from a single crosshead the two blower shafts revolving in opposite directions, which was one of the principal novelties, seemed to work very well indeed; the thrust of one connecting-rod against the guides was neutralised by that of the other, and there seemed to be practically no wear in the guides at all.

Mr. W. Richardson said at Messrs. Platt's works at Oldham a number of these blowers had been in use for some years and had given no trouble; the fans previously used had been taken out and these blowers put in, and in consequence the speed of driving had been very much reduced, while a much higher pressure of blast had

been gained. The blower was now extensively employed throughout the country, and he thought its advantages were very generally known. For mine ventilation however its application was quite a new one, and it was very important that the results of its employment for that purpose should be made known. The two large revolvers acted of course as a combined flywheel, tending to keep the engines to a uniform speed through the intervention of the bevil gearing; and it seemed to him there must be some backlash in the gearing in consequence, and he should be glad to hear something more about this point, as to how the gearing was found to act in the working of the ventilator. If, instead of using bevil gearing, the engines had been placed alongside the ventilator, working direct upon one of the ventilator shafts, and the two revolvers had been coupled together by some wrapping contact, such as ropes or straps, it seemed to him that would have been a more direct way of connecting them, and there would not be the backlash in the gearing which he thought must happen in the present plan. If this mine ventilator could be made to answer, it would be very desirable that it should replace the fan for the ventilation of mines, as it had already done for blowing cupolas.

Mr. PERKINS said he had one of the first of these blowers, which had been put up six or seven years ago, and had worked ever since. It was one with the wood revolvers; he had at first disliked the idea of wood for that purpose, but it had turned out very well.

Mr. E. J. C. WELCH enquired with regard to the blowers for cupolas and smiths' fires, what was the relation between the cubic space occupied by one of these machines and the number of cubic feet which it delivered at each revolution. With regard to the escape valve mentioned in the paper, for relieving the blower from the extreme pressure which there would be when the outlets were suddenly closed, this valve had been done away with at the works with which he was connected, and instead of it a 12 inch vertical cylinder was placed on the side of the frame carrying the engine which drove the blower; and the cylinder piston, which was very

light, was connected direct to the throttle-valve of the engine. The bottom of the cylinder was in communication with the delivery pipe from the blower; and by putting weights on the top of the piston the pressure of the air could be regulated to anything required. With this self-acting arrangement it mattered not whether there were twenty or thirty tuyeres in blast, or only a single tuyere; the blower revolved always at the speed necessary for the supply of air, and no more. A great economy was thus effected over the arrangement by which the blower was always running at one speed and the surplus air was escaping under pressure.

Mr. G. Allan, referring to the wooden revolvers of the ordinary blowers, thought it would be generally agreed that an iron revolver, if made accurately, must be much preferable to one of wood. In two of the blowers which he had under his control some time ago, his experience was that the revolvers were liable to get out of adjustment. In one instance—a blower of No. 7 size—the thickness of the composition which was applied to the revolvers was much greater than would be supposed from the description in the paper, amounting to as much as 1-8th inch or more; and during the low temperature of winter the composition was found liable to shell off and jam the blower: in fact on one occasion it was so jammed that the shafts were bent at the bearings. On another occasion, with another of the blowers, it was found that a little exhaust steam, which under certain conditions was liable to be drawn into the machine, had the effect of swelling the wood, and the revolvers had to be reduced at the surface. Under such conditions he thought there was no doubt that the iron revolvers were preferable, unless the wood ones could be made now in a very much better method. The difficulty with the iron revolvers he presumed was to shape them perfectly true; and he imagined an arrangement would be desirable for adjusting the shafts from time to time, when wear occurred in the machine as it must do; for before the brasses of the bearings were so far worn out as to require new ones putting in, there must be so much wear as materially to affect the accurate fitting of the revolvers. In the Baker blower, also an American

invention, consisting of three revolving drums, which were made perfectly true cylinders and were thus the easiest shape to form with accuracy in the lathe, a simple arrangement for adjustment was provided, to place the drums again closely in contact after any wear of the bearings had taken place.

Mr. A. J. STEVENS considered, in regard to the application of Roots' blower as a ventilator for mining purposes, that the first requirement in mine ventilation was simplicity of construction; and this ventilator seemed to him to depart far from that condition, probably as far as any yet introduced. There appeared to him to be several difficulties in the use of this machine, and it must require considerable care in looking after. The gearing, as already mentioned, seemed a very weak point; supposing a tooth in one of the bevil wheels were to break, the whole machine would probably be destroyed. Also the packing timbers being adjusted within 1-8th inch of the revolvers, supposing any dirt or chips were to get between during working, by being carried up in the current drawn from the mine, an accident might occur. He enquired whether the engines driving the ventilator had been working with any condensing arrangement in the experiments given in the paper.

Mr. A. STEWART replied that the engines driving the ventilator were without any condensing arrangement. In carrying out the experiments given in the paper with this ventilator at Chilton Colliery, the aim had been to follow exactly the plan of the previous experiments made by Mr. Daniel on various other ventilators of the principal kinds in use, given in the former paper in the Institution, the general results of which were reproduced in the present paper for the purpose of comparison with those obtained from the ventilator at Chilton Colliery. In the experiments with this ventilator the mean indicated horse power was taken of both cylinders; and the effective horse power, ascertained theoretically by calculations from the capacity or displacement of the machine, underwent some reduction when taken from actual measurement by anemometer of the air current drawn from the mine into the ventilator; then the

percentage of useful effect was the ratio of the horse power thus measured to the indicated horse power.

In the event of a mine explosion, the superior efficiency of this ventilator over fans or other ventilating machines not having so great exhaustive power would consist in the fact that, if the result of the explosion were to diminish the area of passage through the airways in the mine, then by setting the ventilator to work at maximum speed, with the full power that could be brought to bear upon it, it would be capable of drawing the air through the diminished area of opening, where a fan could not possibly do so. With a fan the exhaustion or pressure attained was only from 4 to 6 inches of water column, whilst the Roots' blowers used for melting iron were working constantly with 20 inches of water; and it was in this greater exhaustive power that they were in advance of previous ventilating machines.

In the use of the blower for engraving upon glass by the sand-blast process, it had been found to answer very well; and there were also various other processes for which it was successfully employed, besides those referred to in the paper. It was not intended to convey any impression that this machine was new; and reference had been made in the paper to Jones' gas exhauster, showing that, while the shape of the revolvers was purposely the same in Roots' blowers as in that machine, the difference was in the proportions of the dimensions; and the arrangements of building up the revolvers with cast iron and wood, as well as other modifications of the construction, were all improvements that had been introduced in this blower by the inventors and by themselves. The revolvers being constructed in some instances of cast iron, and in others of wrought iron and of wood, he thought there could be no objection to the blower on account of the material used, as iron revolvers were employed in every case where wood might not be suitable. At Messrs. Platt's works at Oldham, to which reference had been made, there were fifteen No. 5 blowers, one No. 2, and two No. 1 at work, of the ordinary construction with wooden revolvers; and no fewer than 2000 of the blowers with these wooden revolvers had already been made and were working in different parts of this country. It was

true that in commencing to make them ten years ago they had not been made so complete as they were now. The composition put upon the revolvers had been a drawback in some cases; but that had generally arisen from the composition not being put on in the proper manner by the persons using the machines; the management was left in careless hands without proper instructions, and the composition had sometimes been thrown in, as he had known, a quantity at a time; in such cases, as was to be expected, the revolvers being so close together, the composition clogged the machine and interfered with its working.

With reference to the weight of the mine ventilator described in the paper, a Guibal fan of equal capacity would be 46 ft. diameter and 15 ft. wide, and the weight on the shaft would be at least 40 tons; that was also about the weight of the ventilator at Chilton Colliery, but that weight was there distributed equally upon the two shafts, instead of being all carried upon a single shaft. As to the gearing through which the ventilator was driven by the engines, although great attention had been paid to getting the bevil wheels accurately constructed, there was a little backlash; this however arose from the cushioning of the steam in the cylinders at the end of the stroke, consequent upon the small amount of lead given to the slide-valves of the engines, and if a little more lead were given to them it would take off the concussion or shake that there was at present in the wheels: this would be noticed on referring to the indicator diagrams. The use of these wheels seemed to be considered objectionable in the construction of this machine for a ventilator; but in nearly every piece of mechanism there were toothed wheels of some sort, either spur or bevil, and in this machine it was only a question of proper proportion to determine how long the wheels would last; if they were made sufficiently strong in the first instance, there would be no limit to their durability, and they would last as long as any other portion of the machine. With regard to the liability of anything getting into the ventilator in working, the house containing it was roofed over and kept locked up, so that nothing could get in or interfere with its working; no objection therefore could be urged against the ventilator on

this ground that would not apply equally to any other machine, such as the Guibal fan, if proper care were not exercised. At the extremities of the revolvers of the ventilators there was 6 in. clearance when nearest together, which was amply sufficient to allow of play or wear in the gearing without the revolvers coming in contact with each other. The cost of the ventilator and engines at the Chilton Colliery had been about £3200, and that of the foundations and house about £2300, making the total cost about £5500 for the ventilator, engines, and house complete; this was the first that had been made, and no doubt the cost would be considerably reduced in making others and smaller sizes.

The PRESIDENT moved a vote of thanks to Mr. Carbutt for his paper, which was passed.

The Meeting was then adjourned to the following day.

The Adjourned Meeting of the Members was held at the Institution of Civil Engineers, London, on Friday, 1st June, 1877; THOMAS HAWKSLEY, Esq., President, in the chair.

The following paper was read :—

ON STEAM BOILERS AND ENGINES FOR HIGH PRESSURES.

By Mr. LOFTUS PERKINS, of London.

The object of this paper is to bring before the Institution plans for generating high-pressure steam, say from 250 to 1000 lb. per sq. in., and working it with great expansion and perfect safety, in conjunction with simplicity and durability. Sixteen years ago the author, conjointly with Professor Williamson, read a paper on this subject at a meeting of this Institution in 1861 (see Proceedings 1861 page 94). The Engine and Boiler then described have been in use ever since, and recently became the property of a gentleman who for several years has had another boiler and engine on the same system at work. The boiler and engine of 1861 are to be re-erected at the new works of the Sub-Wealden Gypsum Co., at Battle near Hastings, and are to form part of a steam plant consisting of three sets of boilers and engines &c. on this system. Since 1861 many improvements have been effected, and are embodied in the engines recently constructed and illustrated in the accompanying Plates 15 to 21.

In generating steam of the high pressure required to realise a fuller benefit of expansion, it has previously been found impossible to combine in the boiler great strength and safety with durability: if the former are secured, by reducing the internal dimensions and capacity of the boiler, the impurities passed in are fatal to the latter. In working a marine engine which was designed to use water distilled from sea water, the author found that, although extreme care was taken to separate all the impurities from the water before it was introduced into the boiler, the internal surfaces were in the course of time seriously injured. In the same manner, ordinary marine boilers using surface condensation have been injured when there

has been an insufficient supply of sea water to form a protecting scale on the exposed internal surfaces. This led the author to seek for a remedy, which he succeeded in discovering, and adopted with absolute success. This was the use of nothing but fresh water or distilled fresh water in the boiler, used over and over again, without any admixture of sea water or the products of sea water; and this was easily accomplished, as the machinery in question had been designed to avoid any leak whatever, and the amount of waste that did take place from glands &c. was so small in quantity, that no practical inconvenience was found in providing the small supply of fresh water required to make good the waste that did occur.

The means taken to secure the soundness of all the joints and parts of the machinery were the same as those which had previously proved successful in the manufacture of the high-pressure heating apparatus which the author and his firm have been making for upwards of forty-five years, and which has continued to work with the same water with which it was originally charged, without any destructive effect on the internal surfaces. Many sets of this heating apparatus have been working forty years without decay; and some specimens of tubes from the boiler that was described in the former paper in 1861, which were cut out of this boiler for the Admiralty Boiler Committee in 1874, were found to be in such a remarkably good state of preservation that the committee made a special report on the system, which was laid before Parliament, and the specimens referred to are now shown to the meeting by the kind permission of the committee. The boiler and cylinders of the engine at the writer's works were opened in the presence of the committee for the purpose of examining their condition; and the tubes of the boiler were found to be in a remarkably good state of preservation after having been in use nearly thirteen years, and the piston-packing and valve-rings made of the special metal were found in excellent condition after eighteen months' working without lubrication since last examined. The same engine and boiler, as well as those of the yacht "Emily" which worked five years in the Thames, were also carefully inspected by Mr. I. W. King, Chief Engineer, United States Navy, who found the results very

satisfactory; and in a two days' trial that he made of the yacht "Emily" between the mouth of the Thames and the upper locks, the boiler pressure was maintained at 500 lb. per sq. in. during the greater portion of the time running, and the steam was expanded about 24 times; the yacht was 57 ft. long, 7 ft. 4 in. beam, and drawing 4 ft. of water, with a dead weight or displacement of 15 tons, and it steamed 60 miles in 6 hours on a consumption of 3 cwt. of coke which cost three shillings.

The possibility of using water which did not injure the internal surface of the boiler enabled the author to design the boiler on a system that combines maximum strength and safety. The construction of the Boiler is shown in Figs. 1 to 4, Plates 15 to 17. The horizontal tubes are $2\frac{1}{4}$ in. internal and 3 in. external diameter, excepting the steam collecting tube, which is 4 in. internal and $5\frac{1}{2}$ in. external diameter. The horizontal tubes are welded up at each end $\frac{1}{2}$ in. thick, and connected by small vertical tubes of $\frac{7}{8}$ in. internal and $1\frac{5}{16}$ in. external diameter. The firebox is formed of tubes bent into a rectangular shape, placed $1\frac{3}{4}$ in. apart, and connected by numerous small vertical tubes $\frac{7}{8}$ in. internal diameter. The body of the boiler is made of a number of vertical sections, composed each of eleven tubes connected at each end by a vertical one; these sections are connected at both ends by a vertical tube to the top ring of the firebox, and by another to the steam collecting tube. The whole of the boiler is surrounded by a double casing of thin sheet iron, filled up with vegetable black to avoid loss of heat. Every tube is separately proved by hydraulic pressure to 4000 lb. per sq. in., and the boiler in its complete state to 2000 lb., this pressure remaining in for some hours without showing any signs of leakage. Experience of a very extensive character has proved that this construction of boiler can be worked safely, with great regularity, and without priming, and that the steam produced is remarkable for its freedom from moisture. The area through the vertical connecting tubes is found ample for allowing of the free escape of the steam, and for the prevention of injury from overheating of the tubes in contact with the flame. Injury arising from a prolonged stoppage of the feed supply is a casualty to which all boilers are liable, but with this

construction of boiler the small capacity of the sections reduces to a minimum any danger arising from such injury, and facilitates rapidity of repair.

In Figs. 5 and 6, Plates 18 and 19, is shown the arrangement for using the high-pressure steam in the Engine. The engine has three cylinders; the first A is a single-acting high-pressure cylinder, and the second B also a single-acting cylinder, four times the capacity of the first: these two cylinders are bolted together in the same straight line, and have a common piston-rod. The third cylinder C is double-acting, four times the capacity of the second, and its piston-rod is connected to a crank at right angles to the other crank.

Having safely generated steam of high pressure at say 350 lb. per sq. in., a serious difficulty has to be overcome in using it, from the high temperature affecting the lubrication of the pistons and packing of the glands. These difficulties the author has succeeded in overcoming by introducing the high-pressure steam into the upper end of the first cylinder A, Fig. 6, where there is no gland, and where the piston is formed so as to require no lubricating material. The steam is cut off at about half-stroke in this cylinder, and when it is admitted for the return stroke into the bottom of the second cylinder B, of four times the area, the temperature is so much reduced as to cause no difficulty when brought into contact with the piston-rod gland. From the bottom of the second cylinder B the steam expands into the top of the same cylinder, which is of larger capacity than the bottom, and serves as a chamber, and is in direct communication with the valve-box of the third cylinder C, Fig. 5; this last is double-acting, and is arranged to cut off at about a quarter stroke, and at the termination of the stroke exhausts into the condenser, with a total expansion of about thirty-two times. All the cylinders are jacketed with wrought-iron tubes, as shown in the drawings, which are cast in the metal, and supplied with steam direct from the boiler, the condensed water from the jackets being conveyed to the hot-well. The whole of the cylinders and valve-boxes &c. are enclosed with a double case of thin sheet iron

filled in with vegetable black to prevent the escape of heat, and at the same time to maintain all the parts at a high temperature.

In working these high pressures with great expansion, the ordinary mode of packing the pistons was found unsatisfactory; and to overcome the difficulty the compound piston was devised, shown in section in each of the two cylinders in Fig. 6, and by the sample piston exhibited. The prevalent scoring and cutting of engine cylinders was effectually remedied by the discovery of the compound metal, of which the packing rings are made, which requires no lubricating material. Many cylinders fitted with piston rings made of this metal have been several years at work, and have been often examined, the cylinders showing no signs of wear, the wear taking place on the rings only, which may be easily and inexpensively renewed as required; and experience has proved that with these pistons the longer an engine is worked the more perfect does the surface of the cylinders become, and the less wear results to the packing rings. This metal for piston packing-rings is composed of 5 parts tin and 16 parts copper, and has since been used by several other makers for ordinary engines with great success. When this metal is used, no oil or grease is required to lubricate the cylinders—a great advantage, particularly where the engines are fitted with surface condensers.

The high-pressure pistons in the steamers "Atacama" and "Coquimbo" of the Pacific Steam Navigation Co. were fitted with these packing rings, and it was reported by the superintendent engineer that the cylinders, which were previously rough and slightly grooved, were in the course of two or three voyages, or about 10,000 miles' run, brought up to a beautiful smooth surface, and had since kept in capital order, giving no trouble whatever. After having been once brought up to a smooth working surface, the packing rings did not wear the cylinders; the wear of the rings was also very slight, and the friction greatly reduced, and one-third of the lubrication necessary for cast-iron rings was found sufficient. In the torpedo vessels made for the French Government, Messrs. Thornycroft found these packing rings for the engine pistons a

great advantage, as there was no chance of the cylinders being scored; and they were enabled to run the two hours' trial easily, at the high speed of about 430 rev. per min., without using any oil or grease in the cylinders. In an engine at the Dorking Grey Stone Lime Co.'s works, the manager reported, after $2\frac{1}{2}$ years' use of these packing rings for the pistons, that they required no grease of any kind, and worked the cylinders to a polished face and needed no looking to until worn out; a set of rings lasted about 100 days, working at the usual high steam pressure of 400 lb. per sq. in.

In Figs. 7 and 8, Plate 20, is shown the Surface Condenser used; it is constructed of a number of vertical tubes in such a manner as to be absolutely tight, so as to ensure that the condensing water inside the tubes shall not mix with the water from the condensed steam outside them. The tubes are $\frac{7}{8}$ in. internal and $1\frac{5}{16}$ in. external diameter, welded up at the top end and fixed securely in a tube plate at the bottom. These tubes are fitted with internal tubes, open at both ends, which are fixed in a division plate at the bottom, in order to cause the condensing water to circulate to their extreme ends, the course of the circulating water being shown by arrows in Fig. 8.

In Fig. 9 is shown a small Still, worked by a steam coil, which is used both for marine and land boilers to distil fresh water for replenishing any small waste that may take place in the feed supply. A duplicate apparatus forms part of the ordinary equipment of a sea-going vessel, to furnish steam from sea water for blowing the steam whistle, cooking, supplying distilled water for use of passengers and crew, and for all other purposes where steam is allowed to run to waste.

In designing the machinery described, provision is made for passing any waste steam from the safety valves &c. into the surface condenser, and the great strength of the boilers allows a margin of 100 lb. per sq. in. or more to exist between the load on the safety valves and the pressure required to work the engines. When this system is fully carried out in steamships, the author would deem it quite safe, and more than ample for making good the waste of water from all sources, to provide, beyond the water in the boilers, a supply

of fresh water in the proportion of 10 gall. per 24 hours per 100 Ind. H. P. As an instance of the practical feasibility of carrying out the system of machinery that has been described, it may be stated that a boiler containing only 300 gall., and an engine working at 250 lb. pressure and 250 Ind. H. P., were worked night and day continuously 13 days (one Sunday excepted) without requiring any addition to make good the waste of working, nor at the end of the trial was there any appreciable difference in the water level of the boiler.

The special points that are desired to be brought under notice are :—

1st. The extremely high pressure at which the steam is worked, and the consequent economy in fuel and decreased weight of engines, boiler, coal, and water combined that is necessary to be carried for a given power and distance or time of steaming.

2nd. The absence of internal lubrication with either oil or tallow, thereby avoiding the possibility of corrosion by fatty acids.

3rd. The continually recurrent use of soft fresh-water or rain-water (not distilled sea-water) as the only remedy against the internal corrosion of marine boilers that are supplied with water from surface condensers.

In the indicator diagram, Fig. 10, Plate 21, the two upper diagrams are taken from the working of a pair of marine engines on this plan of 70 nominal H. P. in the steam tug "Filga," and the coal consumed averaged 1·62 lb. per Ind. H. P. per hour. In this case there was no vacuum and no low-pressure cylinder, and the terminal pressure was 21 lb. per sq. in. above the atmosphere; the boiler pressure was 300 lb. per in. With the addition of a low-pressure cylinder and a vacuum, the author considers it may safely be estimated that this system, properly carried out, will realise an average duty of one horse power for each pound of coal per hour.

The President observed that the paper now read, though brief, was a very remarkable one, and raised many new points for discussion.

Mr. Perkins exhibited a number of specimens of the boiler tubes and connections from the boiler at his works that had been taken to pieces, as named in the paper, for examination by the Admiralty Boiler Committee; and also specimens of the piston packing-rings used in the cylinders of the engine, made of the special metal described.

The connections of the main horizontal tubes throughout the boiler he explained were made by means of small vertical connecting pipes, which were screwed into the horizontal tubes with right-and-left-hand threads in the case of all the tubes forming the separate vertical sections above the firebox, being screwed simultaneously into the upper and lower tube (as shown one third full size at AA in Figs. 3 and 4, Plate 17). The ring tubes forming the firebox were connected by "backing-out" joints, like those used in making gas connections, the connecting pipe being screwed with a right-hand thread at both ends (as shown at CC); in putting the rings together the short connecting pipe was first screwed up into the upper ring to double the required distance, and was then backed down into the lower ring; so that, whichever way the connecting pipe was turned, it screwed itself in at one end and backed out at the other. This arrangement gave the means of taking out and replacing any one of the ring tubes forming the firebox, without altering the vertical distance apart between the adjacent tubes above and below. For connecting the main sections of the boiler with the steam collecting tube at top and with the firebox ring tube below, a differential joint was used (as shown at BB), similar to that employed for the Richards indicator, except that the boiler connecting pipe was made cylindrical throughout instead of taper. A separate short connecting pipe was screwed right-hand into each of the tubes to be connected, the threads being 15 per inch, as in all the rest of the joints throughout the boiler; and then these two connecting pipes were united by a coupling socket, screwed right-hand at both ends, but with 11 threads per

inch at the top end and 15 per inch at the bottom; this socket was first screwed down to double the required distance upon the lower connecting pipe, and then backed upwards upon the upper, the differential thread having the effect of drawing together the two ends of the connecting pipes, and thereby compressing a copper washer that was inserted between them to form a perfectly steam-tight joint. All the screwed joints into the tubes of the boiler were made tight by caulking after being screwed up, until they stood the testing water pressure of 2000 lb. per sq. in. The differential joints admitted of taking out and replacing any one of the sections of the boiler over the fire, without interfering with any of the others. It was the construction of the joints in these different ways which formed the main feature in the manufacture of the boilers.

Mr. Olrick remarked that, as Mr. Perkins had brought before the Institution engines and boilers of so totally different construction to the usual kind, it looked well that he could bring forward thirteen years' character as to their satisfactory working, because many practical men who were used to the ordinary mode of producing steam and using it in an engine would have some doubts about the feasibility of this system. In regard to the boiler, which was one of the mainstays of the system, the condition was to have perfectly pure water, and that could only be obtained by distillation from fresh water. In the ordinary system the impurities were carried over from the condensation of salt water, and this proved clearly that there must be a certain amount of impurities in the salt water which could not even be taken out by distillation, and consequently went over into the boiler and injured it; for why should otherwise ordinary boilers that were used in the present compound marine engines not do as well as Perkins's? It certainly seemed strange that this boiler should stand so well, and should have stood so well for so many years. The ordinary cross-tube boilers with tubes parallel to the level of the water always burned at the top of the tubes, in the centre, and not at the bottom. The reason was that the steam accumulated in the centre before it was driven out, and consequently prevented the water from being in contact with the

iron, and therefore it burned. The remedy of course was a very simple one—to tilt the tubes a little, and the steam would then escape and the tubes were not burned. But Mr. Perkins did not tilt his tubes, and stated that he had used these boilers for 13 years in the same manner, and they had never burned. There was a point to be considered in these boilers which was a very material one,—the proper circulation in the boilers; and it was not apparent how there could be proper circulation in them. Taking as an example of proper natural and self-acting circulation an ordinary Cornish boiler with a Galloway tube, there was no doubt a great amount of steam on the internal surface of that tube, and the solid water in the larger part of the boiler outside the flue would sink down, and the mixture of steam and water inside the tube would ascend. Exactly the same system was carried out in a Davey-Paxman boiler, which had tubes in which all the mixed water and steam went up, and the heavy water came down in the outer casing, which made an efficient steam generator; and no special means were needed in these two kinds of boilers for effecting this self-acting circulation. In the Field boiler however special means were adopted for separating the two currents, for the duty of the internal circulating tube was to effect this; and the result of this separation was, as in the two previously mentioned boilers, a perfect self-acting circulation of the water, which made an efficient steam generator. There could not be any circulation in the sense of absolute separation of the heavy and the light current in Mr. Perkins' boiler; and he thought there was only about the same commotion in the water of each tube as in an ordinary tea kettle. The steam simply escaped through the small vertical tubes, and ascended upwards. It was stated, and that was an important point, that there was no priming in the boiler; but he thought that could be easily explained, when it was remembered that, if 1 cub. ft. of water was evaporated under atmospheric pressure, there would be produced 1642 cub. ft. of steam, and when the pressure was raised to 75 lb. there would only be 298 cub. ft. of steam produced from 1 cub. ft. of water. But Mr. Perkins went up to 250 lb. as a minimum, and at that pressure there would only be produced 108 cub. ft. of steam, and at the

higher pressure of 500 lb. only 58 cub. ft.; at 1000 lb. pressure there would be only 30 cub. ft. of steam from 1 cub. ft. of water. That explained why there was no priming, because there was only so small a cubic quantity of steam to ascend and to penetrate the same space.

If Mr. Perkins' system could prove itself satisfactory on being tried on a large scale, and able to stand the same rough usage to which all other boilers in the navy were exposed, there was no doubt that it would be a great improvement on the present system. At the present moment if anything happened to a boiler the ship had to come home, and be taken out of the fleet. But with this plan of boiler in a fleet corresponding to the old line-of-battle ships, a yacht could be asked to give half a dozen tubes to repair the damage done by a shot that had penetrated the boiler; it would indeed be almost practicable to rebuild a whole boiler in a ship if destroyed by the enemy's fire. One point by which Mr. Perkins had shown how to overcome a difficulty of a very practical nature was the piston, which seemed to be very efficient, and was made of a metal requiring no lubrication; and he wished to ask whether the same compound metal was used for slide-valve faces. In the recent failure of the "Thunderer" from breaking down of her eccentric rods, no doubt if such a metal had been used in the slide-valves it would have greatly reduced the amount of friction. It was stated in the paper that the Pacific Steam Navigation Co. used metal of the same description, and only used one-third of the amount of lubrication previously consumed; but that statement did not give a fair idea of the advantage, because it was not necessary to use any lubrication at all; since if lubrication could be dispensed with at 300 or 500 lb. pressure it need not be used at a much less pressure. The two main advantages of Mr. Perkins' boilers were, firstly the very high pressure used, and the consequent small cubic contents of steam produced per cub. ft. of water evaporated; and secondly the absence of lubrication in the engine, for no doubt lubrication pumped into the boiler would in a short time ruin it. There had been seen of late so many mishaps and so much trouble from the boilers in the Royal Navy, that he thought Mr. Perkins had made out a good primâ facie case for his system being tried on a large scale.

Mr. J. R. Ravenhill observed that the boiler described in the paper was stated to be worked with distilled fresh water used over and over again, and nothing but distilled fresh water, and there was said to be but very little waste; and the opinion had been expressed by the author that no detriment would arise to the boiler in consequence of the use of that distilled water. That opinion was exactly at variance however with the results obtained in experiments made some years ago for his own firm by the late Dr. Letheby, to ascertain what effect very pure distilled water would have on wrought iron; the action of the water was found to be extremely rapid upon the pieces of wrought-iron plate which were then tried.

With reference to the small vertical tubes connecting the horizontal tubes in the boiler, he could not but think, as a practical boiler maker of a good many years' experience with marine boilers, that some trouble would be found to arise from the introduction of those small tubes, at their junction with the larger tubes. The longest distance had not been mentioned that any vessel had run which had been fitted with that particular form of boiler; but if the boiler when set to work on board a steamer was not found in every way efficient, and if anything like a hitch occurred with those small connecting tubes, he thought very serious trouble would arise. The great point he had always aimed at was simplicity of repairs as far as practicable; and he thought the taking out of any portion of the boilers for repairs, as had been suggested, would be found a rather troublesome job on board ship when under weigh, and the ship would in all probability have to run to the nearest port to do the work in harbour. This form of boiler he believed had been recommended by the Boiler Committee appointed by the Admiralty for trial in the navy, and some of the boilers he thought had been ordered, but he had not heard anything more about them. The question of a good high-pressure boiler was at the present time he considered the great question among marine engineers.

Mr. A. Paget supposed that, with regard to the effect of pure water on wrought-iron plates, it was considered to be established beyond doubt by chemical experiments that distilled water did

damage wrought-iron plates under certain circumstances; but he had been led to doubt whether this was always the case in the practical working of boilers by an instance that had come under his own notice. A small boiler had been put down some years ago to work a non-condensing engine in a situation where there was a difficulty in finding a water supply; and as there happened to be a large area of roofage available, the rain water was collected from it into a soft-water cistern for supplying the boiler. He had expected at the time that the boiler would be very speedily destroyed; but on the contrary it had now been at work 15 years, working with nothing but the purest soft water that could be obtained in a small country town where there would be very little impurity to get to it. The boiler had been opened the other day for inspection, and was in as good a condition as he could imagine a boiler to be in after 15 years' use. That he thought was a more practical test than a laboratory experiment.

Mr. J. R. Ravenhill observed that rain water collected from roofs must necessarily contain some impurities derived from the roofs, such as soot; and no rain water would be found to be so pure as that used in the experiments he had named, which had been distilled over and over again, until it had been made as pure as was thought possible. A further proof of the injurious action of distilled water in boilers was afforded by the fact that the late Mr. Edward Humphrys, whose name was so well known in connection with marine steam navigation, when he commenced making engines with surface condensers, fitted the "Mooltan" with a small boiler which was employed for some days in distilling water for the purpose of using in the main boilers; and the result of that trial was that the plan was given up. Soon afterwards also, when some engines were being made for the Peninsular and Oriental Steam Navigation Co., by his own firm, the same thing had been tried and had been given up; the water distilled in the boilers was itself the purest that could be obtained at the East India Docks, and was he believed the water supplied from the East London Water Works, which came from the chalk.

Mr. C. F. T. Young remarked that of the two conflicting statements as to the action of pure water on wrought iron—distilled water being found to destroy it, while rain water did not destroy it—both might really be right; but until the conditions were known under which the water had been used,—that is, the degree of heat and pressure employed, he did not think that either fact could be taken as conclusive one way or the other. It was known that, when boilers with brass tubes were left exposed at the natural temperature of the air, galvanic action took place, and corrosion very quickly injured the plates; but under steam those boilers lasted a long time without corrosion. He thought therefore the pressure and the degree of heat at which the water was kept in the boiler had some influence on the result.

Mr. Jeremiah Head observed that rain water had always a little carbonic acid dissolved in it, which it got from the atmosphere, whereas of course distilled water would have nothing of the kind. The carbonic acid in rain water was sufficient, as was well known, to enable it to dissolve carbonate of lime, which was not soluble at all in pure water.

Mr. E. B. Marten said he had seen Mr. Perkins' boiler several times, and had the opportunity of examining it when it was opened for showing to the Boiler Committee of the Admiralty, and he was very much surprised to find how well it had stood. He had always considered it the very best type of the small boiler principle, and thought that others were more or less imitations of it; it was the only one that avoided the immense difficulty of having to heat up a lot of cold fresh water, and then to get rid of the scale that was made. He had watched almost all other boilers that had only a small steam space, and found the great difficulty was that they evaporated a large quantity of water in a very small space, and the deposit had to remain in the part of the boiler that had to do the most work. There was also this difficulty, that in sudden alterations of pressure the immense increase of bulk of the steam formed in the water so highly heated, when the pressure had fallen, made it

boil over directly or prime. In the case of this boiler, as there was no vent to the open air, and no chance of such a sudden demand of steam, that effect was not produced, because the moment the pressure was a little reduced, enough of the water evaporated to produce again the heavy pressure; therefore the boiler had not those sudden over-boilings called priming. He also thought this was the only instance where the true system of using those small-space boilers was carried out to the full extent by making water a reciprocating part of the engine,—making it part of the machine, so that the same water was used over and over again. Whenever those kinds of boilers were discussed, they seemed to call up a sort of antagonism on the part of those who had long used and advocated the Lancashire boiler, under the idea that they would supersede the Lancashire boiler in all kinds of work; but he had no doubt the Lancashire boiler would continue to do the bulk of the steam-producing work of the country for a long time. So many cases arose however where a very high pressure was required, that he thought more favour ought to be given to those who were trying experiments or doing something to introduce a boiler that would really be perfectly safe at very high pressure. He thought also there was very great error in supposing that work could not be carried on in the ordinary way unless there was a boiler with a very large bulk of water ready prepared to form steam if there should be any sudden demand; it was only a matter of detail, that could well be got over if there were any need for it, when these boilers were tried on a large scale. In reference to the question of circulation, he thought the reason this boiler had no trouble on that account was that circulation was not wanted unless there was great heat in one part of the boiler, in which case it was then required to bring a sufficient quantity of water to that place to take up that heat. In this boiler, whenever heat happened to be concentrated upon any tube, there was a tremendous rush to that particular place, as the tubes were all open to one another; and there being no deposit left behind, the steam took away the heat that would otherwise injure the tube, and no trouble was felt. Instead of trying to make the circulation of the boiler always travel a long way to ensure preservation of the heated part, this boiler acted like the modern

constant-supply mains in a town, which were all connected together, and wherever there was a demand there was a rush to that particular point; and that was the reason why this boiler did not suffer from want of circulation. In reference to corrosion, he thought both the statements that had been made were true. Nothing was more corrosive than soft water or distilled water, and he found it so in the enormous quantity of corrosion that was seen outside of boilers, where the condensed steam from leaky fittings dropped upon the boiler and soon corroded the plate away; but in this boiler there was not the same chance of corroding the boiler away, because there was no outside leaking, and, as to the inside, when the water had been in a little while it had taken up all the iron that it could dissolve, and there remained then only the action of what extra supply of water had to be admitted. It was sometimes considered that, because there might be a chance of a hitch on board ship to such a boiler as this, it ought to be adopted with very great caution; but he might say that boilers afloat were subject to very frequent hitches, and the boilers of the navy seemed especially to have suffered from very serious hitches; therefore the chance of one of those hitches ought not to deter from using those boilers afloat.

He wished to hear how the boiler behaved when the demand for steam entirely stopped. In ordinary boilers, when the engine stopped, the bulk of water absorbed the heat and gave it out again when needed. He should also like to know whether it was necessary by special means to check the fire in such a case; and whether the boiler mentioned as having worked successfully was worked hard or not during the time referred to when it showed no signs of wear.

Mr. H. CHAPMAN asked if the non-liability to corrosion in Mr. Perkins' boiler might not be due to the deposition of magnetic oxide upon the surface of the iron, caused by its exposure to the action of steam at so high a pressure and temperature, which was the basis of Professor Barff's process for the protection of iron and steel from corrosion.

Mr. D. Adamson said he thought those who knew him best would not conceive for a moment that he was frightened at the idea of the Lancashire boiler or any other boiler having a special preference. He trusted that whatever was to the interest and to the advantage of steam users and of mankind would be the thing that would prevail and have the preference of the entire body of engineers of that Society. He felt deeply interested in the matter, and was very pleased that the present paper had been brought forward by one so eminent in experience in dealing with high pressures and the consequent high temperatures. In considering the subject he would begin with the boiler; not that he held it to be a more important element than the steam engine, as he thought the engine required as much accumulated experience as the boiler itself to work off such a high pressure and consequent high temperature. He did not think the boiler was necessarily imperfect because it had fewer chances of having a good circulation than ordinary boilers; but he was strongly impressed on the other hand with the idea that a certain quantity of cubic contents of water was required for absorbing the heat from a given surface of iron in a given time, and that the heat produced from 6 sq. ft. of firegrate could not be passed through 1 sq. ft. of surface, whatever might be brought in contact with it. If that was true, it gave a limit to the power of absorption, and there must be a limit to the extent of reduction that was advisable in the quantity or cubic contents of water in the boiler in proportion to the heating surface, and the heat that could be thrown upon the material of the boiler in a given time. In the case of this boiler, the first thing done was to get up a high temperature, and having passed it to the structure itself, the water was then bound to take up the heat by bringing it in contact with the whole of the series of tubes. Then came the principle, what quantity of water was wanted as well as surface; but the effect of the quantity would be diminished in proportion as the temperature was increased. The rate of ebullition depended upon the pressure that was in the boiler, compared with the temperature of the water at the same time; and if in this boiler, with 300 lb. per sq. in., the pressure was only reduced 1 lb.,

the tendency to produce ebullition would be the smallest possible amount; but in the case of the boiler of a locomotive, in starting from a station the pressure would drop down probably 10 to 20 lb., and rapid ebullition or boiling consequently followed. The boiler now shown would be able to carry its water perfectly quiescent so long as the pressure was removed only slightly at any time; the higher the pressure and the smaller the reduction in a given period, the less tendency to violent ebullition or priming. He apprehended the water, in receiving heat from the high temperature of the metal, transmitted it to its adjoining particles without ebullition at all; and the high pressure being combined with the high temperature, there was no ebullition, but simply a system of stratified temperature was in the metal itself received by the water, and no tendency to prime or boil. If that view was correct, then the boiler was not likely to suffer on the upper surfaces of the tubes, or even at the joints, unless the pressure was rapidly reduced and a great demand made upon the water for a change of temperature, and then rapid ebullition would ensue. So far then the quantity of water might be reduced in proportion as the rapidity was limited of any reduction of the pressure; but under all practical circumstances he could hardly think that a boiler of this class, with horizontal tubes coupled up at the ends, with a long horizontal surface, was the right structure to convey the heat into the water. Contingencies must necessarily arise in the working of any steam engine or steam boiler, in which the pressure became quickly reduced, and then a rapid ebullition would follow. Particles of steam would adhere to the upper portions of the tubes, or get interlocked, and great disturbance in the interior was likely to be produced by an increase of temperature. There was hardly an iron in the country that was not subject to a great reduction of strength when exposed to a temperature ranging from 500° to 700°, and at such heats it was easily destroyed by percussive force—not even excepting Low Moor iron or mild steel now justly so popular. He thought that would explain the destruction that had often ensued with the Howard boiler: it did not get quit of the heated particles under the circumstance of a reduction of pressure in the interior,

and a superheating of the metal consequently took place, making that construction of boiler exceptionally unsafe. With regard to the old Lancashire boiler of large surface, he could say that in the 2000 he had put to work there had not been any explosions; this arose first from good workmanship, and further because the structure protected itself; but that could not take place in a system of tubes, where the heat could not be conveyed to the surface after it had been absorbed in a reasonable amount of time. Hence all classes of structures of this sort would require very considerable modification before they could be practically introduced to meet the wants of a large class of consumers, either for stationary or for marine boiler purposes.

With regard to the engine itself, he congratulated the author of the paper, not only for introducing the engine, but for his courage in handling the high pressure that he had employed. He believed on the whole there was more cause of alarm on the question of temperature, than simply on that of high pressure. By reducing the diameter, or by thickening the metal, a pressure of several tons per sq. in. could be carried: it was not a question of ingenuity of construction, but simply of proportion in the strength of the metal employed. What was wanted was a boiler that would meet all the contingencies that might arise in practical working. In reference to the engines, he wished to enquire the reasons for adopting a treble action, and for not adopting a more extensive compound action. He had himself worked treble cylinders for 14 years, for driving a cotton mill of about 750 H. P., and at 80 lb. steam pressure. The results obtained were, according to his experience, higher economy than either the single or the double-cylinder engine gave with the same pressure. A doubt might arise as to why there should be three cylinders, or whether any other number was better; and his own answer was that it had become a result of long practical experience, that a compound engine with two cylinders, at limited pressure, would work as a practical engine with more economy than a single-cylinder engine. It gave out a more steady force, and was subject to less wear and tear, and it had a tendency to lose less of its pressure by the slipperiness or by the leakage of its surfaces, and by contingencies that might

arise in practice in innumerable ways, besides considering that tremendous steam-hammer action which must necessarily arise if there was only one cylinder. Then the argument was, that if it was found in practice that two cylinders developed economy, security, and uniformity of action better than a single cylinder, it was not because there was any greater economy of the expanding spaces, but that there was a greater economy in the freedom from shock, and in the reduced difference of pressure between the opposite ends of the same cylinder, causing less loss from leakage as well as condensation, although there were two pistons and two sets of valves, instead of one in the single-cylinder engine. Then he thought there must be a serious question as to how far such a compound action was to be limited in the number of cylinders: and in the quadruple-cylinder engines that he had constructed and worked so successfully, he took the same view, that the economy of the increased number of cylinders arose from the reduction in extent of the change of temperature in any one vessel. He was ready to admit that the single-cylinder action was by far the best, if it were possible to hold high-pressure hot steam in a cold vessel without loss: if a high temperature steam was employed, it must be held in a high temperature vessel. Then the question naturally occurred, what was the limit of the increase of the number of cylinders, and increase of steam pressure? It was stated in the paper that this engine had worked with 250 lb. steam at 1·60 lb. of fuel per Ind. H. P. per hour, and it was suggested that had there been a condensing apparatus the consumption would have been reduced down to something like 1 lb.; but he thought there must be some mistake in the matter, and did not see how the amount of work could be performed by the action of steam below atmospheric pressure, or effect anything like so great a saving. He thought there was a source of loss in the great difference of temperature that must take place between the cylinders. In the quadruple engines that he had referred to, 60° was about the maximum change of temperature in any one vessel, and from his own experience he inclined to think that a still lower change of temperature was the most economical as regarded the working of the steam; and hence more vessels or more cylinders were required as the steam pressure

was increased, and by so doing more valve and piston checks were obtained between the boiler and the condenser, bringing in another important simple elementary principle. In the quadruple-action engines now driving at 616 Ind. H. P., there was a consumption of fuel at 110 lb. boiler pressure of 1·90 lb. per Ind. H. P. per hour; that is, including the keeping the steam up in the boilers for 14 hours daily, while the engines were only working 10 hours. In that case the 110 lb. steam was received in a cylinder 17 in. diameter, this first cylinder yielding about 28 times its nominal H. P., without any shocks more than were ordinarily due to low pressure; but if the same pressure were put on the last cylinder, which was 42 in. diameter, the percussive action would be so violent as to render the whole structure that of a breaking-down machine, and a great increase in the flywheel shaft would be required for keeping the journals anything like cool: whereas when high pressure and temperature was handled with small areas, there was a complete command over it.

As to the non-corrosive qualities of distilled water, he thought the explanation given, that the water was distilled from pure water to begin with, probably accounted in a large measure, if not altogether, for the difference between the results obtained in the working of those boilers and that of the marine boiler, where distillation had taken place from an impure water. Water from chalk was known to be impure; and when it was distilled it might carry some of its impurities forward, which would be injurious to the life of a boiler. Hence probably in the use of very high pressure steam greater care would be taken to secure a pure water to begin with.

Mr. T. R. CRAMPTON enquired whether in Mr. Perkins' experiments he had tried the quantity of water evaporated per hour by a given amount of surface, because that was a very important element in determining the value of a boiler. Boilers were often heard of evaporating 9 or 10 lb. of water with 1 lb. of fuel, whilst another boiler evaporated only 7 or 8 lb.; but on enquiry it was found one had 30 or 40 sq. ft. of surface per cubic foot of water evaporated per hour and the other only 7 or 8 sq. ft. These were most

important questions, and should be kept in view when discussing the matter. With regard to this boiler, it appeared an established fact that it not only worked but had been working well; but he was not clear how the evaporation was effected, or how any circulation at all arose, and why there was no accumulation of steam and no destruction of the boiler. He had himself a very strong view with regard to these high pressures and great extent of expansion, and thought they were carried too far when practically considered; there were many things to be considered in dealing with the question. The theoretical value due to the expansion decreased immensely as the number of expansions increased; and to obtain the small gain which was possible theoretically by increasing the number of expansions beyond a moderate extent, it was necessary to increase the number and strength of cylinders and other parts, and also to strengthen the boilers; that meant great wear and tear for a very small gain of fuel. From what he had seen, the principle was being carried too far. He had an opportunity of working an engine where he could ascertain the exact quantity of power that was used by pumping water; and designed the engine for a steam pressure of 70 lb. to 80 lb. above the atmosphere, 30 lb. of steam with four times effective expansion being sufficient for the work. He made experiments week after week, with different steam pressures and corresponding changes of expansion, taking the quantity of water evaporated for the engine and the quantity delivered by the pump into the tank in each case; the engine was small, only developing about 11 Ind. H. P., which was rather against the value of the experiment. He found the result was that with 30 lb. steam and five times expansion one Ind. H. P. was obtained with 18 lb. of water per hour during a continuous week's work. Then 40 lb. steam was tried, increasing the expansion to do the same amount of work; and then 50, 60, and 70 lb. steam pressure, going up to eleven times expansion; there was perfect steam-jacketing of the cylinders on the sides and ends, and all steam surfaces of every description were most effectively coated with non-conducting material, full benefit of the expansion being thus secured. The result was that a theoretical value was gained in the diagrams

with the higher pressure, but the total work done or the water pumped into the tank was no more with eleven times expansion than with only five times; and he therefore came to the conclusion that the 20 or 25 per cent. that ought to have been gained theoretically with the higher expansion was all absorbed in the extra friction, loss by condensation, and a variety of other effects which were produced by the higher pressure. No other case had come under his notice where the question had been worked out in that way, by taking the actual weight of water pumped into the tank in each case; but this was on rather too small a scale for a general conclusion; there would not be so much loss in larger engines. He thought the time had now come when, before going into very high expansions and very high pressures, the question should be officially investigated by the Institution, in order to ascertain the facts, and thus prevent young engineers from working in a wrong direction.

Mr. A. Paget suggested that, as the same views respecting the desirability of limiting the steam pressure and the degree of expansion had been expressed by Mr. Crampton at the last Liverpool Meeting, it would be advantageous if he would communicate a paper upon the engine with which results had been obtained that were so much at variance with the generally received opinion about the utility of expansion and the relative value of compound and single-cylinder engines. It might be found that there was something in the valves, packings, stuffing-boxes, or other arrangements of the engine, which accounted for the exceptional results, when the whole circumstances of the case were fully stated and discussed.

Mr. T. R. Crampton did not consider there was anything extraordinary or new about the results he had obtained with moderate expansion in a single cylinder; one H. P. had been obtained with 18 lb. of water per hour 35 years since to his knowledge. But there was an importance in establishing a fact, and he hoped that the Institution would endeavour to take means for settling such a vital point. This was not a question of number of cylinders for

expanding steam in, but simply the losses occasioned through the extra wear and tear of the increased number of parts necessarily required by the use of very high steam and great expansion, compensated for by the small saving of fuel effected.

Mr. C. Cochrane thought there was one make of high-pressure boiler that might justly be considered a safe and sure boiler,—the Root's boiler, a description of which he had given to the Institution some years ago as used at his own works, and it was certainly growing in favour with him year by year. As regarded the subject of corrosion, he was not quite sure it was correct to say that pure water did corrode iron. He did not believe in the corrosion of iron by pure water condensed from steam in the inside of a boiler. His belief was that the corrosions which had been reported, and which were so frequent in boilers internally, were due to the formation of acids by the oils used in the engines, which acted upon the iron and absolutely destroyed the junctions of the plates and rivets. He thought the case of internal corrosion was entirely different from that dropping of distilled water from the condensation of steam on the outside of a boiler where the influence of the atmosphere operated, supplying the oxygen by which external corrosion could take place; and in that respect he believed there was a total difference between the external corrosion of a boiler and the internal corrosion. He thought at any rate it had yet to be shown that the ordinary notion that pure water did destroy a boiler was a correct one, and he did not think himself it was correct. As regarded getting rid of the steam from the boiler, his own practice with fourteen Root's boilers went to show that, when a boiler was designed, by the diminution of the diameter of the tubes, for working at high pressures, it must be limited to working at those high pressures, otherwise the boiler would not get rid of the steam, and for the simple reason that steam at a high pressure was compressed into a much smaller bulk. In the case of Mr. Perkins' high-pressure boiler there were 20 atmospheres pressing a cubic inch of steam into 1-20th of its bulk; therefore the space this steam occupied in travelling along the horizontal tubes was small, and the little arch of tube above it so short, that the

conducting power of the iron was sufficient to keep it cool whilst the little top layer of steam travelled right and left until it could find a vertical ascent into the steam chamber above.

Mr. J. F. Flannery thought that increase of economy must be obtained from the increased steam pressure and increased ratio of expansion, even allowing for the loss of friction incurred. In the use of high-pressure steam there was first to generate the steam, and then to use it in the engine; but there were difficulties under both these heads, and he thought the greater difficulty was in the generation of steam. The only difficulties in the use of the high-pressure steam in the engine appeared to consist in the lubricating material burning up and in the packing of the piston rods; and Mr. Perkins had introduced a most elegant and ingenious method of overcoming these difficulties, which seemed very likely to overcome them to a very great extent indeed. But in respect of the arrangements shown for the generation of the steam, he could not adopt quite the same opinion. It was very true that the boiler did work well, but that might be only under certain conditions which could not be expected to be provided generally. Under such careful supervision of the inventor a very ingenious and complicated machine might work well, whereas under the care of people less interested, and ordinary engineers and stokers, the results might not be nearly so good. The boiler was very nearly identical with some which were tried at sea in the "Montano" and the "Dacota;" and when those boilers had been at sea only a few hours, the bottom tubes nearest the fire got hot and cracked, and caused injury to some of the men in the stoke-hole. Amongst the reasons given as to the cause of the accident, the more correct appeared to be that the vertical necks which connected the horizontal tubes were too small in proportion to the cubic capacity of the tubes, and that the steam rushing up by ebullition carried water with it, and left the bottom of the tubes exposed to burning. It might be that the introduction of the water into the bottom of the tubes direct from the feed pipe, in the boiler now shown, might do away with the necessity for the descent of water to take the place of the steam which had been generated. It

appeared from the paper to be considered that there was not any descent of water, and no circulation in the ordinary acceptation of the term, but that the bottom of the tubes should be supplied direct from the feed pump with water to make up for the evaporation. If that was so, then the working of one or two examples of those boilers under special care might give good results; but it was well known that feed pumps were liable to derangement when least expected, from choking or jamming of the valves and other causes, or from carelessness or incompetence on the part of the attendants. In the case of ordinary marine boilers, where there were 16 or 18 tons of water present, the inconvenience of the feed pump stopping would not be so great, but the injury arising from the stopping of the feed supply would be greater in the case of a boiler containing only a small quantity of water than in the case of an ordinary marine boiler. But whether or not it was considered that Mr. Perkins had fully succeeded in the attempt to produce a proper generator, his spirit and enterprise in that direction must be admired. It was known to be the question of the day, and all engineers were looking with great interest to the result of the labours of Mr. Perkins and other inventors, who were travelling over this ground. It might be that the time had already come when a successful high-pressure engine was accomplished; but if not, he believed that the time would certainly come. It would be useful if the weight of the engine described in the paper, and also of the boiler, could be given per Ind. H. P., more particularly as applied to marine purposes.

The PRESIDENT considered that a subject deserving of further notice in connection with the engine described in the paper was the metal of the piston packing-rings, of which specimens were exhibited, and by means of which lubrication was dispensed with in practical working. This would be an important consideration in connection with the air engine, which was well known to be a very good engine—in fact in many instances better than the steam engine, except in the one respect that no one had yet been able to make a piston which would resist the tearing effects of dry air. In the engine described in the paper the steam used was dry steam

and of about the temperature at which air would be worked in an air engine; therefore it appeared to him that if these piston packing-rings would answer in this steam engine they would also answer in an air engine. He should be glad to know why the particular composition of metal employed for the packing-rings produced that particular effect; and hoped there were some present who could offer an explanation. He noticed that the metal contained more than twice as much tin as usual in gunmetal, being 1 to 3 instead of about 1 to 7.

Mr. E. J. C. Welch remarked it was not often that the Institution had the advantage of having brought before it an invention which, while it had all the interest of novelty about it, was supported by so many years' successful working. The question of compound engines was a very comprehensive one; the main object was to divide up the temperature so that the same cylinder should not receive a charge of very high steam, and at the next moment be exposed to a charge of that which was at a comparatively low temperature. Therefore the question of the number of cylinders must depend upon what was the ultimate range of temperatures between that of the boiler and that of the condenser. He did not think it was a question that could be settled by any mathematical formulæ, but one that could only be determined by a very comprehensive range of experiments.

The question of jacketing cylinders was one about which there was some little ambiguity, because the fact was not always taken into account that there was so much work done by the heat transferred from the jacket and that so much water was condensed there. Taking as an illustration an absolute pressure in the cylinder of 50 lb. above zero, and expanding it down to an absolute pressure of 5 lb. before it entered the condenser, there would be in a jacketed cylinder 11·22 lb. of water per hour as the theoretical quantity necessary to develope one Ind. H. P. inside the cylinder; but while that was being done the jacket must yield up heat sufficient to condense 2·36 lb. of steam into water, so that the theoretical weight of steam required to produce one Ind. H. P.,

and used under the conditions stated, was 13·58 lb. That was calculated, not by the hyperbolic curve, but by what was deemed to be the true curve of expansion in a jacketed engine, where the temperature was not really maintained, because so long as the steam was in a state of watery vapour it would absorb heat rapidly through the jackets; but the moment it became dry it would scarcely absorb heat at all. The steam in the cylinder at the end of the stroke was not of so high a temperature as at the beginning: it was still a dry gas, but a gas of a lower temperature and of a correspondingly lower pressure, and the curve of expansion was not therefore an isothermal one. In an unjacketed engine, and under the same conditions as before, there was only 11·84 lb. of steam required per Ind. H. P., which was 1·74 lb. less than in the jacketed engine; but then that would assume that in the former case the cylinder did not condense a large quantity of steam at the beginning of the stroke. Now there was no doubt that in an unjacketed engine, the moment the steam entered the cylinder, a large portion of it was condensed; and as the stroke went on, the cylinder was again reduced in temperature, by reason of the expansion that took place; therefore it was not quite easy to show theoretically the exact saving which would be effected by a jacketed cylinder. In practice however it was known that the jacketed engine did yield very much better results than an unjacketed one. Attention had very properly been drawn to the important point that there was no relation between the horse power of an engine and that of the boiler; they were perfectly independent things, and as long as engines were spoken of as developing so many horse power per lb. of fuel the subject could not be properly understood. The economy of an engine depended entirely on the weight of steam required to develope one indicated or actual horse power, and on that alone. The economy of a boiler depended entirely upon the weight of fuel required to produce that steam at the pressure which was required for the engine. If in a similar engine to that which was mentioned the pressure were taken at 150 lb. instead of 50 lb., the saving theoretically was found to be about 18 per cent. by using the higher pressure. In the engine described in the paper

the pressure of steam was taken at 500 lb., while the temperature of that would be about 470°; at 250 lb. it would be only 400°; but if carried up to 1000 lb. it would be 550°. Now as the total heat of steam at atmospheric pressure was 1178 units, and each degree of increase of temperature in saturated steam only raised the total heat 0·305 unit, at 250 lb. pressure the units of heat were 1235·34; at 500 lb. 1256·69; and at 1000 lb. 1281·09 units. There was consequently only about 8·75 per cent. more heat in a pound of steam at 1000 lb. pressure than there was in the same weight of steam at atmospheric pressure.

Now although the primary object in compounding an engine was to divide the great range of temperatures between the two or more cylinders, still in most cases it was of even greater importance that each cylinder should yield an equal amount of power; and it was only under certain special conditions that the two objects could be attained at the same time, and when this was not so it then became necessary to consider the division of power first. The following formulæ provided for such a relation between the areas of the two cylinders as that they would each give out the same amount of power to the crank shaft. Putting x = area of the high-pressure cylinder in square inches, and y = that of the low-pressure; H = total indicated horse power to be provided for; P = initial absolute pressure of steam in lb. per sq. in.; F = its final pressure in high-pressure cylinder; T = its final pressure in low-pressure; R = number of times expanded in high-pressure cylinder; M = mean pressure in high-pressure cylinder; V = number of revolutions per min.; S = length of stroke in feet of high-pressure piston; s = that of low-pressure: then in the case of a jacketed engine

$$x = \frac{8250\,\mathrm{H}}{\left\{\mathrm{P}\,\mathrm{R}^{-1}\left(17 - 16\,\mathrm{R}^{-\frac{1}{16}}\right) - \mathrm{F}\right\}\mathrm{V}\,\mathrm{S}}$$

$$y = \frac{x}{\mathrm{R}}\left(\frac{\mathrm{P}}{\mathrm{T}}\right)^{\frac{16}{17}} \times \frac{\mathrm{S}}{\mathrm{s}}$$

In the case of an unjacketed engine

$$x = \frac{8250\ \mathrm{H}}{\left\{\mathrm{P}\,\mathrm{R}^{-1}\left(10 - 9\,\mathrm{R}^{-\frac{1}{9}}\right) - \mathrm{F}\right\}\mathrm{V}\,\mathrm{S}}$$

$$y = \frac{x}{\mathrm{R}}\left(\frac{\mathrm{P}}{\mathrm{T}}\right)^{\frac{9}{10}} \times \frac{\mathrm{S}}{\mathrm{s}}$$

If the values of x and y be calculated upon the principle of the hyperbolic curve, then

$$x = \frac{8250\,\mathrm{H}}{\left(\mathrm{M}-\frac{\mathrm{P}}{\mathrm{R}}\right)\mathrm{V\,S}}$$

$$y = \frac{x\,\mathrm{P}}{\mathrm{R\,T}} \times \frac{\mathrm{S}}{\mathrm{s}}$$

A very important question which affected all engines, whether ordinary or compound, was that of balancing, which seemed to be very imperfectly understood. It was often assumed that the balancing of an engine simply meant the balancing of the flywheel, but it really meant the balancing of all the forces,—not only the force of gravity, but also the moving forces. Now in every engine it was of the greatest importance that the weight of the reciprocating parts should be taken into consideration, as well as their strength. Having made them sufficiently strong,—especially in an engine which cut off very early with a correspondingly high initial pressure,—it might be necessary to make them heavier, so that their inertia might absorb additional force at the beginning of the stroke and give it out at the latter part; and it also became necessary that the compression at the end of the stroke should be properly calculated to absorb the momentum exactly.

Mr. E. B. Ellington wished to ask whether it was quite certain that there was a mechanical separation of the steam from the water in the lower tube of the Perkins boiler. It occurred to him that the steam and water which was heated to a sufficient temperature for the steam to escape might assume a spheroidal or other mechanical form which would permit it to rise through the cooler water, and not take the form of ordinary steam until it got into the upper tubes. That might account for the boiler working without apparent circulation. With reference to the steam-jacketing, he observed that the lower-pressure cylinder was steam-jacketed, but could not see that there was likely to be any advantage, but rather the opposite, in steam-jacketing the low-pressure cylinder, as it appeared to him that the effect of jacketing would be to re-heat part of the steam which was condensed in the cylinder, the difference in temperature between

the steam in the jacket and in the cylinder being so great. In the two first cylinders any effect produced by the jacket tended to increase the work done by the steam in the following cylinder, but the effect of jacketing upon the last cylinder would simply be to re-heat a portion of the steam which had been condensed through the work done, and to pass that into the condenser as free steam and so carry away the heat which was in the jacket.

Mr. C. Hawksley would be glad to know whether any experiments had been made by using the water over and over again as proposed in the paper, and also by allowing the steam to escape without condensation, the water evaporated being replaced by distilled fresh water. By such experiments perhaps some light might be thrown upon the question of the action of the water upon the boiler.

Mr. E. A. Cowper observed that there was not any doubt about the expansion curve or the true action of steam in a cylinder. Some years ago he drew out the expansion curve which he now showed, founded upon the principle that the total heat in steam, sensible and latent, was the same in steam of all pressures, and he had repeatedly proved the correctness of this curve in actual work, and in various steam-jacketed cylinders. There was nothing new about it, but it was satisfactory to know that the expansion curve founded upon that theory was practically correct. He wished to call attention to one point about the indicator figures that had been alluded to, as to the lower part of the figure "not being very valuable." He had always been strongly in favour of having a good vacuum, and under ordinary circumstances there was no difficulty in getting 13 lb. in the cylinder; and if that was obtained, the base line of the indicator figure was so low that the expansion could be carried a long way farther than would be effective with an inferior vacuum. As to the actual pressure of steam to be employed, he had a preference for a convenient pressure of 50 lb. to 60 lb. above the atmosphere. The lower part of the indicator figure at moderate pressures was decidedly the most valuable; and

if the initial pressure was run up to ten atmospheres, the portion that was thus added to the area of the indicator figure was small in proportion to the large amount that was obtained below five atmospheres by the expansion that was practicable with a good vacuum. He had proved this practically with an engine working up to 2148 Ind. H. P. in the "Briton," which was the first compound engine in H. M. Navy. On the measured mile, going full speed, the consumption was only 1·98 lb. coal per Ind. H. P., and, when going 10 knots, only 1·3 lb., which he believed was the lowest consumption ever attained. That was using steam of 55 lb. above the atmosphere, cutting it off and expanding it in one cylinder, and then dropping the steam down into an intermediate reservoir, and cutting it off and expanding it in a second cylinder, so that there was a little notch in the expansion curve between the two cylinders, or in other words the true expansion curve was not obtained for this small distance. The cylinders and the reservoir were all steam-jacketed at ends and sides, so that the steam was slightly warmed throughout its whole course of working. Steam as it passed into a cylinder, if it was not steam-jacketed, was condensed to a large amount, and that steam was again evaporated in the cylinder towards the end of the stroke. The cylinder could never be got to a higher temperature than half way between the temperature of the condenser and the temperature of the high-pressure steam; and the cylinder always chilled the steam and condensed a portion into water, causing a loss of coals by so much steam passing through in the form of water instead of in the form of steam. He quite agreed therefore with the paper that the low-pressure cylinder should be steam-jacketed as well as the high-pressure. He thought that, the largest portion of the power obtainable being produced by the moderate pressures he had spoken of, there was but a small margin of gain to be got by very high pressures; the question was entirely a practical one, and a very large one, in all its details, including not only the question of very peculiar boilers and very pure water for them, no grease in the cylinders for pistons and slides, and high temperature of such parts, but also the multiplication of cylinders, and great variations in rotative power. It should be borne in mind that the most uniform

rotative power that could be produced by cylinders and cranks was obtainable from two cranks at right angles, with the steam cut off very nearly at half stroke in each. Three cranks did not give nearly so uniform a power.

Mr. J. A. R. Hildebrandt quite agreed with the opinion that had been expressed, that under certain circumstances more work could be produced from low-pressure steam than from high-pressure steam; and he had himself in various cases reduced the pressure of the steam employed and obtained better results, whereas in other cases he had increased the pressure with advantage: it was of course entirely a question of the special circumstances. One point that struck him as very remarkable in the paper was the statement respecting the self-lubricating metal, that in a certain condition the cylinder metal was abraded by it, and then it ceased to wear the latter altogether. In reference to the action of water on iron, it appeared to him that there was much misapprehension prevailing; it was perfectly well known by experiments in the laboratory that iron would decompose steam into its elements, but how it was that a certain amount of steam was not decomposed in the boiler was an interesting question. At the same time, he thought it quite impossible that really pure water, without free oxygen, could have any effect upon iron. There appeared however to be a considerable misapprehension as to what pure water really was; rain water was far from being pure, and it was well known that there was not only carbonic acid but also a considerable quantity of ammonia in rain water. There was no doubt that these and various other chemical ingredients were the cause of certain actions, and it would be exceedingly interesting and useful to know what those various effects were.

Mr. R. E. B. Crompton remarked that boiler fittings were known to give a good deal of trouble, and he thought with so high a pressure as 500 lb. they would have to be handled very carefully to keep them tight. In reference to the new metal, which contained more tin than usual, he wished to ask whether it was not more brittle than

usual, and whether any difficulty was experienced from its brittleness. Also with respect to the pump, whether any special arrangement was required for meeting the very high pressure. As pump valves were liable to give a good deal of trouble at pressures of 100 lb., it would be interesting to know how Mr. Perkins overcame the shock and wear that came on the valves when pressures of 500 lb. were used.

Mr. Perkins replied, respecting the enquiry about the "Atacama" and the "Coquimbo," that when the Pacific Steam Navigation Co. applied his metal for the piston rings in those vessels they were afraid to use it for the slide valves at the same time. He told them that there was no occasion to use oil in the engine if all the rubbing surfaces were made of this metal, but they only used it for the piston rings; and adhered to cast-iron slides, which were used with oil, and that was the only reason why oil was used in those vessels. In reference to the action of pure water on iron, he thought it was a settled fact that pure water in a hot boiler had no effect upon iron, whether it was in the case of bright iron or of iron covered with an oxide. He showed samples of an iron tube that had been seven years at work, at the very high pressure of 2000 lb. per sq. in., in one of the portable steam ovens of the Government service that were examined by the Boiler Committee, and no action at all had taken place upon the iron. The water in the tube was also tested by the Government analyst and found not to contain anything, and the consequence was there was nothing but pure water in the tube. The amount of sediment had evidently got dissipated; the tube only held about half a pint of water, and it had been at work seven years with pure water.

The President enquired whether anything had been put upon the internal surface of the tube; there appeared to be a black oxide upon it.

Mr. Perkins replied there had not been any coating put on, but all the tubes were no doubt covered with black oxide. Dr. Barff had seen the experiments, and had examined the tube to see whether

it had become covered according to his process; because that tube being kept up to a temperature of 550° and in the presence of steam, if it were perfectly clean originally, as in Dr. Barff's process, it would no doubt be covered with a black oxide as he covered iron. Before operating upon the iron he had to deoxidise the surface of the metal; but that pipe was not clean at first, but left in the ordinary condition of manufacture, so that he did not suppose that magnetic oxide could really be formed upon it. A remark had been made about the joints being liable to be weak in this boiler; but he had one in the small boat "Emily," which he had for five years exposed to continual knocking about the Thames, and had never had any trouble with any of the joints, and was confident that if the boiler were now proved at 2000 lb. per in. it would be found absolutely tight. In that boiler some of the old tubes were used that had been thirteen years previously at work in another boiler, so that in point of fact the tubes of the Emily's boiler had been as long as eighteen years at work. With regard to the repair of these boilers, he might say that he made a boiler capable of evaporating 100 cub. ft. per hour in a ship with a crew of only five men. Such a boiler could be made in a month; the men could readily put the boiler all together provided they were supplied with the pieces, and there was no trouble about making any of the pieces. In the construction of these boilers, hydraulic joints were used, and none of the boilers had ever suffered from leakage except when they had got red-hot, and they got red-hot if they were allowed to be short of water. In reference to the circulation of water in these boilers, there was no doubt circulation going on, and it was very rapid indeed, but he did not think it was a true circulation of water. In all those boilers that were worked hard,—such as a fire-engine boiler or one of the torpedo vessels,—immediately on firing hard the water suddenly rose to a great height; and in his boiler it rose higher than in any other, and the harder the firing the more it rose. In such a boiler as this it must not be expected to get superheated steam; it was found that, however hard the firing was driven, it made no difference to the hot steam; the water foamed up in a similar manner as it did in the high-pressure water-heating apparatus. The low-pressure water

apparatus, in circulating, circulated by the difference of the heat of the water, and if the water was heated over about 180° or 200° it immediately stopped circulating and boiled over. In his own high-pressure heating apparatus, when the fire was lighted no circulation took place at all till the water began to boil; it then foamed up the blow-pipe, and there was evidently a circulation that was very rapid. But there was a great mistake about this circulation; it was thought that the actual circulation of water was rapid, but it took twenty minutes for the water to travel 400 ft., that was when there was something like 100° difference of temperature between the hot and cold water. In this boiler for instance, before the temperature of the water got up to 212° he did not suppose that there was any circulation at all, but directly it began to boil it foamed up the short tubes, and went first one way and then the other. In these boilers there had been no trouble with the heating of the tubes; immediately the tubes got hot they began to bend down, the bottom of the tube then expanding more than the top, because of the intense heat at the bottom. With regard to the contents of the water in the boiler, it was about equal in the amount it evaporated to the locomotive boiler. The boiler in the little yacht Emily would go about a quarter of an hour without pumping, but it would go for 50 hours without pumping if there were not any steam taken away from it. The cubic contents of the Emily's boiler were very small, but the evaporation was small too. There was about 9 sq. ft. to each cub. ft. of water evaporated per hour, taking the whole external surface of the tubes, both steam and water. Of course the larger surface put to a boiler, the better duty it did. It was difficult to ascertain exactly what a boiler did evaporate, if the appliances were not very well arranged; but he thought the boiler shown in the drawings evaporated nearly 12 lb. of water per sq. ft. per hour, with 70 sq. ft. of surface.

Mr. Bramwell enquired what was the temperature of the escaping gases.

Mr. Perkins said the temperature of the escaping gases of that boiler, working at 250 lb., was about 500°, but there was some

uncertainty about the accuracy of the pyrometer. A question had been raised about the reduction of steam pressure in the boiler, and there was a good experiment on that point in the Emily. The boiler worked at 500 lb.; it was a three-cylinder compound engine. When coming to a stopping place the steam was blown off into the condenser, to condense the steam and put it back into the boiler. Knowing this, $1\frac{1}{2}$ minute before coming to the stopping place the expansion was taken off; that was, the steam was let into the high-pressure cylinder and also into the low-pressure cylinder, and the boiler dropped from 500 lb. of steam to 260 lb. in the $1\frac{1}{2}$ minute. At that time the steam must be evaporating at a tremendous rate, but there had never been any trouble; probably it was evaporating five or six times as rapidly as when the boiler was working regularly.

The question about the destructive action on iron was also answered by the sample tube; that had been kept at 500° temperature, and had been forty years in the heating apparatus, and was not in any way deteriorated. He believed the best tubes were made at the present time that had ever been made; but it was certain that the tubes forty years old were quite as good as, if not better than, new ones. He did not think that any temperature between 500° and 600° could ever hurt iron. In reference to the special metal for piston packing-rings, the brittleness of the metal had been enquired about, but there was not any difficulty from this, as it was only used for piston packings and slide valves. The pumps were fitted with cast-iron valves and cast-iron seats ; gunmetal valves and seats used to be employed, but it was found that they were not of any use. There was no rust taking place in any part; in ordinary engines it was found good to make the valves of brass, but in this they were made of cast iron. The only parts that were made of the special metal were those that could not be oiled—every rubbing part; and the cast-iron pistons themselves were not allowed to touch the cylinder, but there was a liner of this metal put round. He thought the reason why it wore so well was that it was so brittle that it would not hold any particles as a grinding lap. He had a case of an engine working with ordinary cast-iron pistons and very hard cylinders and rings; in ten days—night and day work—$\frac{1}{4}$ inch was

taken out of the cylinder, and the rings were all worn away. When the cylinder was opened it was said to be in a beautiful condition, but when measured it was found about $\frac{1}{4}$ inch larger diameter. Since the special metal had been used, there was no necessity to use hard cast iron in the manufacture of the cylinders; the softest iron might be used, and he thought soft iron was better, because in the first place it was very much easier to turn, and then it was sooner brought up to a surface. It generally took one set of rings to get the cylinder into running order, and to get the surface up to the perfect polished state. He found with the little boat that the longer the engine worked the better it was. With regard to what had been said about the risk of incompetent men in charge, he had to remark that every one at first thought that this was a very difficult machine to work. But it was really only difficult when a man came to it with a great knowledge of the old-fashioned plan of working, and thinking that he must treat the engine in the same manner. Some of these engines had been put in charge of men accustomed to ordinary engines, who used to put a great deal of grease in; but if grease was put in the machine, it ruined the whole; it burnt in the cylinders, then went into the boiler, choked the boiler up, and stopped the condenser. But a labourer not acquainted with other engines would drive it as well as possible, and there was no necessity for having an engineer further than to look after the bearings. In the Emily the ordinary piston packing-rings were first used, and there was great irregularity in the working, sometimes a good result was found one day and a poor result another day; but directly the special metal rings were put in, the working was always right. One reason why a great many marine engines primed was the leaking of the pistons; in the Emily the piston was very small, only $2\frac{1}{2}$ in. diameter, and every three months a new set of rings was put in, costing only about a shilling each; six rings were put in the whole piston. With that plan a good vacuum could always be maintained, and the cylinder was never altered in shape. In reference to the action that took place in the high-pressure heating apparatus, he might mention that he worked it at his own house twelve months without putting any

water in, and at the end of the twelve months, when the screwed plug at the end was opened, the gas that came out could be lighted. It was hydrogen no doubt, but where it came from he did not know; it might be supposed to come from the iron taking up the oxygen, but whether that was so or not he did not know, and though there was a great deal of gas the tubes never showed any deterioration. When the tube now shown was opened by the Boiler Committee, the question was raised whether there was any gas in it, and care was taken with the experiment to ascertain this, but there was no sign of any gas.

Mr. BRAMWELL remarked he might mention that he had put up Mr. Perkins' heating apparatus in his own house about five years ago, and it required water but once a year. He had weighed the water each time, and the average supplied was only about $1\frac{3}{4}$ lb. On first unscrewing the cap to put in the water, and applying a light, there was a hydrogen flame; it lasted a very short time, and evidently arose from only a small quantity of gas; each year the flame had been repeated, but he thought it was less and less each year.

The PRESIDENT remarked that he had had a great deal to do with this question of corrosion of iron—corrosion by hot water, corrosion by steam, and corrosion by cold water—on a very large scale. Now what he found was that pure water, so long as it remained pure, was not the cause of corrosion; and there was this important illustration: if water was distilled several times over in a flask and a needle dropped in, and the mouth of the flask closed up, the needle would remain bright and there would be no corrosion at all; but if on the other hand oxygen was allowed to become interstitially incorporated with the water, corrosion immediately set in. And under another state of circumstances, if there was impure iron,—iron which would set up galvanic action in water, and would separate the oxygen from the hydrogen so as to produce nascent oxygen,—there was an enormous amount of corrosion immediately produced, accompanied with pitting if it were inside the boiler. So that with pure water there might

under one set of circumstances be no corrosion at all, and under another set of circumstances there might be very considerable corrosion. But there was another condition: if grease was admitted into a boiler, the fatty acids would be formed, as was the case when Mr. Hall brought out his original external condensers; then the water went round and round, circulating continuously through the engine and the boilers; the boilers were in a few months almost totally destroyed, and it was only after considerable investigation that it was discovered that it was due principally, though not always, to the action of the fatty acids. Mr. Perkins took care that no fatty acids should go into his boiler. With regard to the question of the piston packing, if it were true—but the experiments had not been made on a very large scale—that that particular metal enabled engines to be worked without the use of grease in the cylinder, then it was possible that very valuable machine, valuable under certain circumstances, but not under all circumstances—the air engine—might be constructed, an engine which he had seen work beautifully and very effectively and very economically, but not for long together. Respecting the pistons, there was another matter to be mentioned; pistons were generally made too narrow. The bearing surface upon the piston ought to be deep, for the reason that the passage of steam was in the inverse ratio of the square root of the depth. That was an important thing, but generally neglected; and he was satisfied that, instead of making the piston bearing surfaces of 4 to 6 in. depth, if they were made 9 or 12 in. and a light pressure put upon the cylinder, there would be much less leakage of steam than there was now. About jacketing the cylinders, he knew a very curious illustration of what occurred in a jacketed and non-jacketed cylinder. Many years ago he purchased in Cornwall a single-acting engine made upon Sims' plan, with a high-pressure cylinder standing on the top of a low-pressure cylinder; the high-pressure cylinder was jacketed, and the low-pressure cylinder was not jacketed. When the engine was started she went beautifully, made the whole length of stroke, and worked on in that way for some quarter of an hour; but afterwards began to shorten the stroke by an inch at a time, until at the end of an hour or an hour and a half she fell 18 in. short

of her stroke. That was a rather puzzling circumstance at first, but it was found that by stopping the engine, blowing steam through, and starting again, she went as well as ever. Then it occurred to him that this effect was produced by a diminution in the diameter of the largest cylinder, by reason of its being colder at one end than the other; and upon measuring the cylinder, which was a large one, he found actually that the difference of diameter was 1-8th in. at the end of this period of an hour and a half when the engine fell off 18 in. in the length of stroke. Now that never occurred in the upper cylinder; it kept its diameter. The lower cylinder contracted at the bottom, showing the advantage of jacketing, if it was only for the purpose of keeping the cylinder of a uniform diameter, and preventing the amount of friction which in that case had the effect of diminishing the stroke of the engine in the way mentioned.

He then moved a vote of thanks to Mr. Perkins for his very interesting paper, which was passed.

The following paper was communicated :—

SUPPLEMENT TO NOTES ON THE EARLY HISTORY OF RAILWAY GAUGE, RESPECTING THE ORIGIN OF THE 4 FT. $8\frac{1}{2}$ IN. GAUGE.

COMMUNICATED BY THE SECRETARY.

At a former meeting of the Institution a paper on the Early History of Railway Gauge was communicated by Mr. William Pole, F.R.S.; and in the course of the discussion upon the paper it was stated that the original Railway Gauge, instead of being 4 ft. $8\frac{1}{2}$ in., as at present existing, was 4 ft. 8 in., and that the Stockton and Darlington, which was the first public railway, was originally laid 4 ft. 8 in. gauge, and was afterwards altered to 4 ft. $8\frac{1}{2}$ in. gauge, in consequence of that having become the general railway gauge of the country. The result of subsequent enquiry that has been made upon this subject has been the confirmation of the above statement, and the addition of some further interesting information respecting the origin of the present 4 ft. $8\frac{1}{2}$ in. gauge, which clears up a point not before understood, and corrects some errors in previously published accounts. It is therefore thought desirable for this information to be recorded in the Institution Proceedings by means of the present supplement to the above paper.

The Stockton and Darlington Railway, which was opened in 1825 (the fiftieth anniversary of its opening having been recently celebrated), was made 4 ft. 8 in. gauge inside the rails, and 5 ft. gauge outside the rails, these being 2 in. width, of wrought-iron rolled fish-bellied, with half-lap joints, and weighing 28 lb. per yard; a small portion of the line was laid with cast-iron fish-bellied rails. A specimen of the original wrought-iron rails is upon the table, which has been kindly sent by Mr. John Anderson of Middlesbrough. This gauge of 4 ft. 8 in. inside and an even 5 ft. outside the rails appears to have been at that time and for a

long period previously the regular gauge for the colliery tramways worked by horses, that being the gauge of the chaldron coal wagons in general use; and when locomotive engines were introduced they were consequently made the same 4 ft. 8 in. gauge. The original engine that opened the Stockton and Darlington Railway, named "Locomotion," which was made by George Stephenson at Newcastle, and is now preserved at Darlington Station, was made 4 ft. 8 in. gauge, and remains so at the present time, the gauge between the wheel tyres being 4 ft. 5 in.; the tyres are cast solid with the wheels.

The following information respecting the Stockton and Darlington gauge has been kindly supplied by Mr. Mac Nay, the Secretary of that branch of the North Eastern Railway. In the original Acts of 1821 and 1823, under which the railway was made, there was not any gauge specified; but in the subsequent Act of 1828 (three years after the opening) for extending the line from Stockton to Middlesbrough, it was provided "that the distance between the inside edges of the rails *shall not be less* than four feet eight inches, and the distance between the outside edges of the rails *shall not be more* than five feet and one inch." This is the earliest case known of railway gauge being fixed by Act of Parliament. The 4 ft. 8 in. gauge continued upon the Stockton and Darlington line for fifteen years, until the opening of the main North line between York and Darlington in 1840, when the gauge was altered for the purpose of removing the obstruction then experienced in the interchange of traffic, by allowing any wagons of other railways to run upon the line; as previously only those of the wider-gauge wagons that had thin flanges could be taken on the line. The Stockton and Darlington was however only altered to 4 ft. $8\frac{1}{4}$ in. gauge at that time; the reason for not making it the full 4 ft. $8\frac{1}{2}$ in. being that most of the wagons employed on the line were the old chaldron wagons, which were slack to the 4 ft. 8 in. gauge, or had excessive side play, and the line being at that time laid mostly with stone blocks, having no tie between the rails, was liable in bad weather to get wide in gauge. The subsequent alteration to the present full 4 ft. $8\frac{1}{2}$ in. gauge was carried out gradually as the course of repairs and the relaying of the line gave opportunity; and this

alteration was greatly facilitated by the circumstance of the rails being laid on blocks, and not tied together by transverse sleepers as in the later construction of permanent way.

Information has been also supplied by Mr. Carson of the North Eastern Railway, Stockton, respecting the Clarence Railway in the same neighbourhood (opened in 1838 for passenger traffic by locomotives and worked previously by horses), that the gauge was originally 4 ft. 8 in., and this was altered to 4 ft. 8¼ in. about 1842, and the gauge was subsequently made 4 ft. 8½ in.

In reference to the gauge of the early colliery lines previous to the making of the Stockton and Darlington Railway, the following information has been supplied by Mr. Cuthbert Berkley of Gateshead, manager of the Marley Hill and Springwell Collieries, Newcastle. The Springwell Colliery Railway, one of the oldest in England, was laid to 4 ft. 8 in. gauge, and this was only altered about 1854, when the Springwell line was connected to the Marley Hill and other collieries, which were already in connection with the North Eastern Railway. The difference of the gauge was then found out by running the North Eastern Railway wagons over the Springwell line; the wagons would run, but the gauge was found very tight, and the platelayers' gauges were consequently altered from 4 ft. 8 in. to 4 ft. 8½ in., and the new wagons afterwards put on the line were made for the 4 ft. 8½ in. gauge.

The Liverpool and Manchester Railway, which was the second public railway, was opened in 1830, five years after the Stockton and Darlington; and the conclusion drawn from the information received is that it was commenced at the Manchester end on the same gauge of 4 ft. 8 in., being laid by platelayers taken from the Stockton and Darlington, and using their old gauges. In reference to this the following information has been received from Sir John Coode: "It was stated to me personally by Mr. George Stephenson, that when the platelayers went from the Stockton and Darlington to the Liverpool and Manchester line they took their gauges with them as parts of their stock of tools, and these gauges were used as a matter of course in laying the rails." The original engine, the "Rocket," that first ran upon the Liverpool

and Manchester line at the competition in 1829, for determining whether locomotive or stationary engines were to be adopted for the working, was made 4 ft. 8 in. gauge, as shown by evidence preserved at Messrs. Robert Stephenson and Co.'s factory, Newcastle. During the progress of the line however the gauge was settled to be 4 ft. $8\frac{1}{2}$ in. The following information on this subject has been supplied by Mr. Thomas L. Gooch of Saltwell, Gateshead, who was engaged in the construction of the Liverpool end of the Liverpool and Manchester Railway under Mr. George Stephenson: "There was much discussion during the construction of the line about curves and the self-acting value of the conical tyre in relieving the pressure of the flange against the rail, and the consequent need of a certain amount of play in the gauges of wheels and rails; especially as considerably higher speed was contemplated (even before the 'Rocket' was produced) than that on the Stockton and Darlington Railway. I venture to think therefore that the extra half inch was given to meet these considerations, and that this was the true origin of the 4 ft. $8\frac{1}{2}$ in. gauge."

The conical tyre appears to have been first used on the Liverpool and Manchester Railway, the previous tyres having been all cylindrical; and as an increased play between the rails would necessarily be required in order to give effect to the conical tyre, the most likely conclusion appears to be that the extra half inch was then added to the gauge for that purpose, thus increasing the original 4 ft. 8 in. to the present 4 ft. $8\frac{1}{2}$ in. gauge.

The same gauge as the Liverpool and Manchester Railway, 4 ft. $8\frac{1}{2}$ in., had to be used for the Grand Junction and the London and Birmingham Railways, forming the through communication which was opened eight years later, in 1838, from the Liverpool and Manchester line to London; and 4 ft. $8\frac{1}{2}$ in. became consequently established as the standard dimension for the gauge.

In several of the succeeding railways, as in the following list, the original gauge was increased half-an-inch more to 4 ft. 9 in.; but these were subsequently altered, and 4 ft. $8\frac{1}{2}$ in. has been since adhered to as the standard gauge.

RAILWAY GAUGES.		Original. ft. in.		Present. ft. in.
Stockton and Darlington	opened 1825,	4 8	...	4 $8\frac{1}{2}$
Liverpool and Manchester	„ 1830,	4 $8\frac{1}{2}$	...	4 $8\frac{1}{2}$
Grand Junction	„ 1838,	4 $8\frac{1}{2}$	...	4 $8\frac{1}{2}$
London and Birmingham	„ 1838,	4 $8\frac{1}{2}$	...	4 $8\frac{1}{2}$
York and North Midland	„ 1839,	4 9	...	4 $8\frac{1}{2}$
Birmingham and Derby	„ 1839,	4 9	...	4 $8\frac{1}{2}$
Chester and Crewe	„ 1840,	4 9	...	4 $8\frac{1}{2}$
Manchester and Birmingham	„ 1840,	4 9	...	4 $8\frac{1}{2}$
Manchester and Leeds	„ 1840,	4 9	...	4 $8\frac{1}{2}$

Some information respecting the original gauge of the Newcastle and Carlisle line has also been received through Mr. George Dove of Carlisle. This line was in progress during the making of the Liverpool and Manchester, and the first portion opened was 4 ft. 8 in. gauge; a part of this was single line, and afterwards doubled by adding an extra rail on each side, thus leaving the intermediate space between the two lines only 4 ft. 8 in.

The PRESIDENT then announced that he was instructed by the Council to state that they had concluded an agreement for the occupation by the Institution of an excellent set of suitable apartments on the ground floor of No. 10 Victoria Chambers, Victoria Street; and that a Committee had been appointed for the purpose of furnishing these apartments, and making all other arrangements requisite for effecting a prompt transfer of the Institution from Birmingham to London, and for disposing of the interest of the Institution in the premises in Birmingham.

He also announced that the Summer Meeting would be held at Bristol on Tuesday 24th July and following days, instead of the time previously named.

Mr. A. PAGET then moved a very hearty vote of thanks to the Council for the most energetic and prompt way in which they had carried out that which they knew to be the wish of the Members, the speedy removal of the Institution to London; and remarked that he esteemed it an honour to be permitted to move that vote.

The motion was carried by acclamation.

The PRESIDENT moved a vote of hearty thanks to the President and Council of the Institution of Civil Engineers for granting the use of their rooms for the meeting, which was passed.

The Meeting then terminated.

Arrangement of Ventilator at Chilton Colliery, Ferryhill.

Fig. 1. *Vertical Section.*

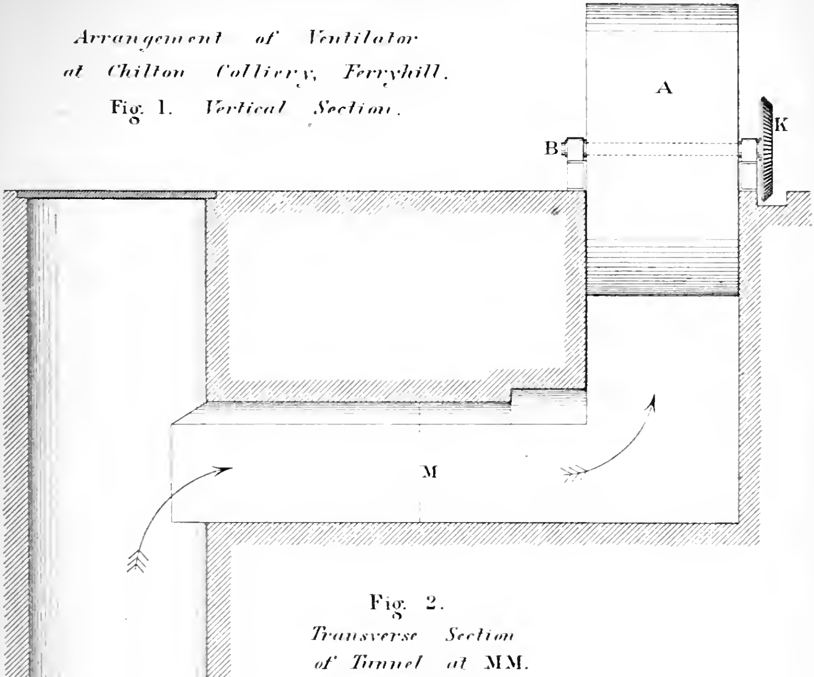


Fig. 2. *Transverse Section of Tunnel at MM.*

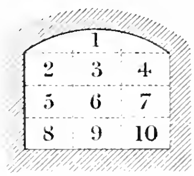
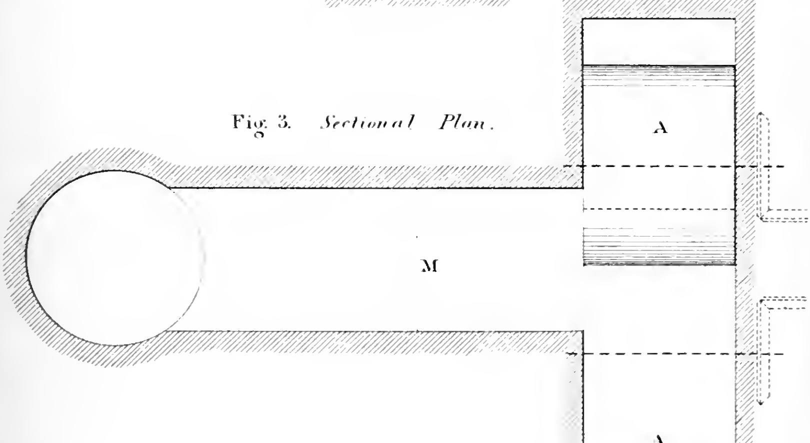


Fig. 3. *Sectional Plan.*



Scale 1/200 th

10 5 0 10 20 30 40 *Feet.*

ROOTS' MINE VENTILATOR &C.

Ventilator at Chilton Colliery.

Fig. 4. *Transverse Section of Ventilator.*

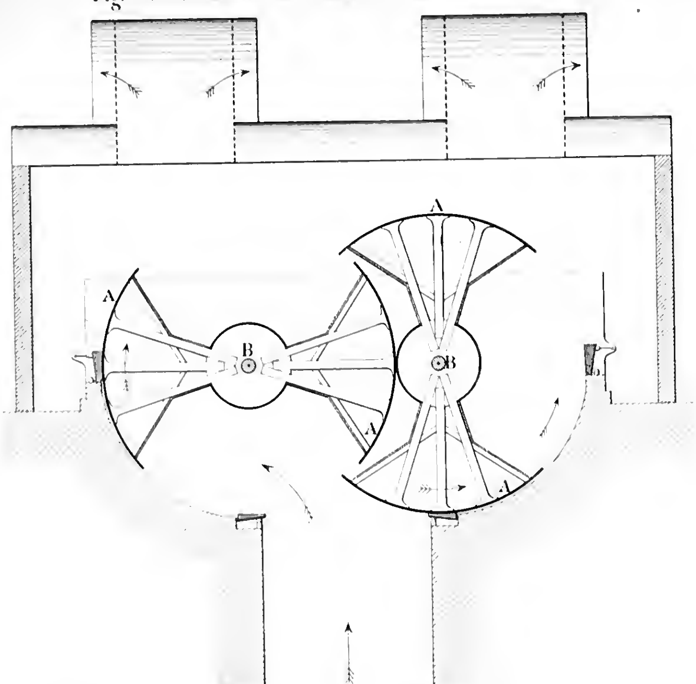
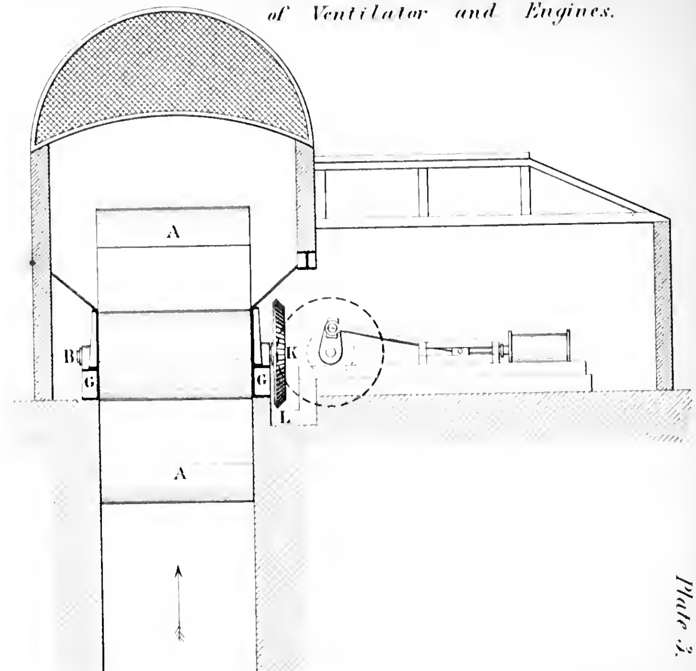


Fig. 5. *Longitudinal Section of Ventilator and Engines.*



(Proceedings Inst. M. E. 1877.)

Scale 1/200th

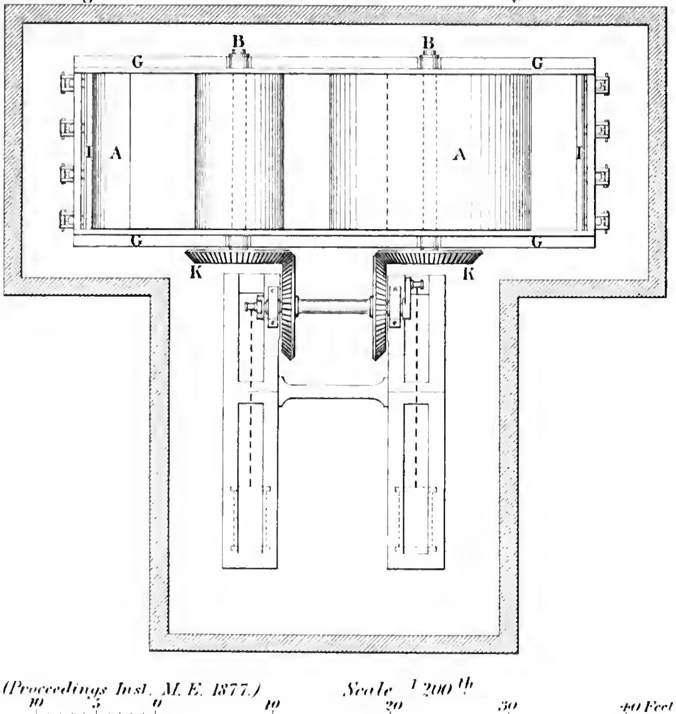
10 5 0 10 20 30 40 50 *Feet*

Plate 3.

ROOTS' MINE VENTILATOR &C.

Ventilator at Chilton Colliery.

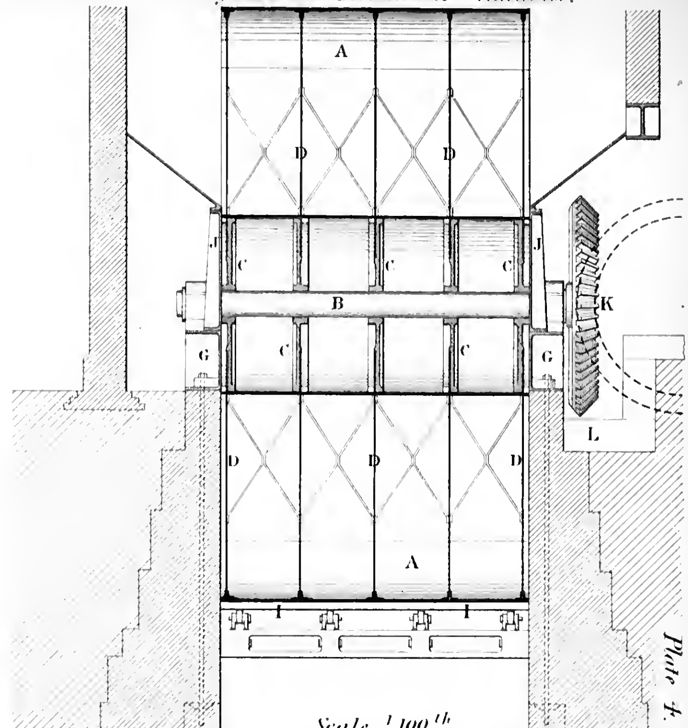
Fig: 6. *Plan of Ventilator and Engines.*



Scale 1/200th

Fig. 7.

Longitudinal Section of Ventilator.



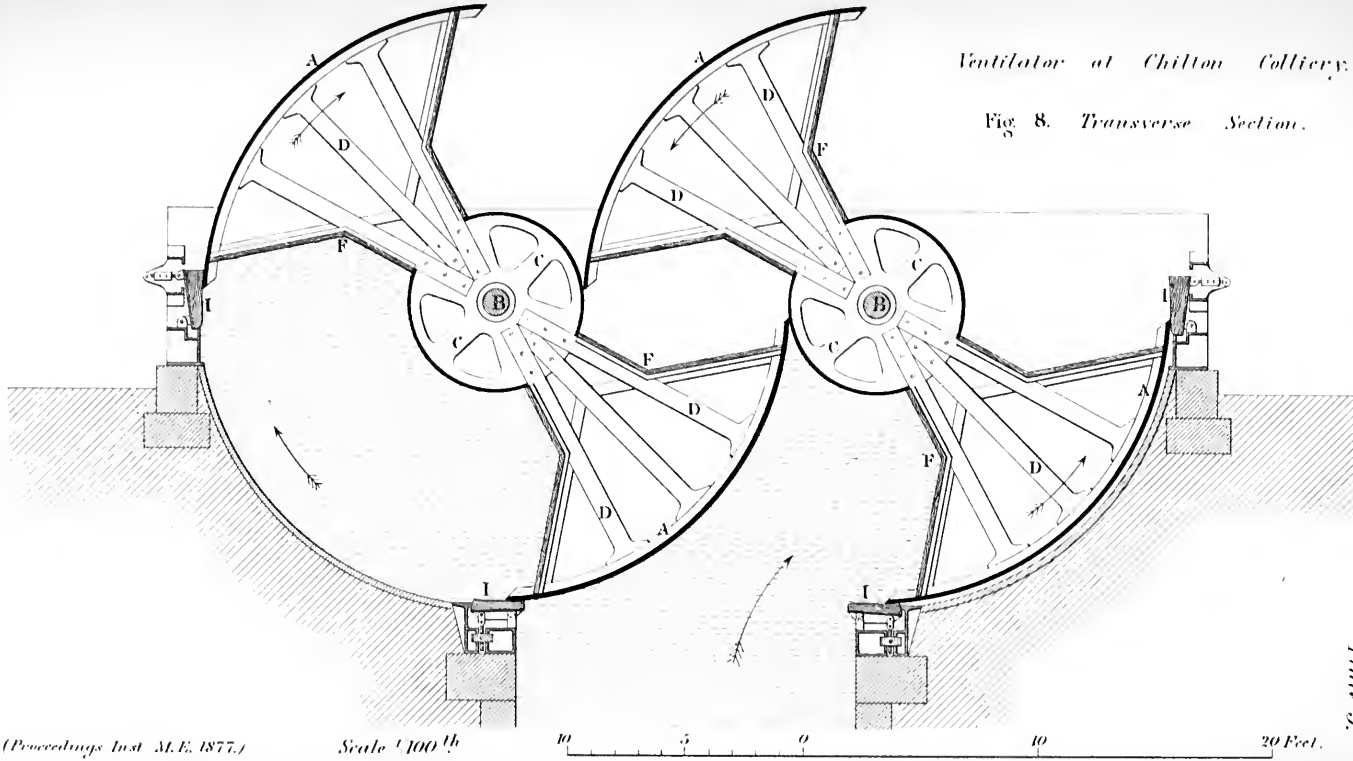
Scale 1/100th

Plate 4.

ROOTS' MINE VENTILATOR &C.

Ventilator at Chilton Colliery.

Fig. 8. *Transverse Section.*



(Proceedings Inst. M.E. 1877.)

Scale 1/100th

Plate 5.

ROOTS' MINE VENTILATOR &C. *Plate 6.*

Indicator Diagrams from Engines driving Ventilator at Chilton Colliery.

2 *cylinders,* 28 *in. diam.,* 4 *ft. stroke.*

Fig. 9. *Experiment* 4 (*Table* III.)

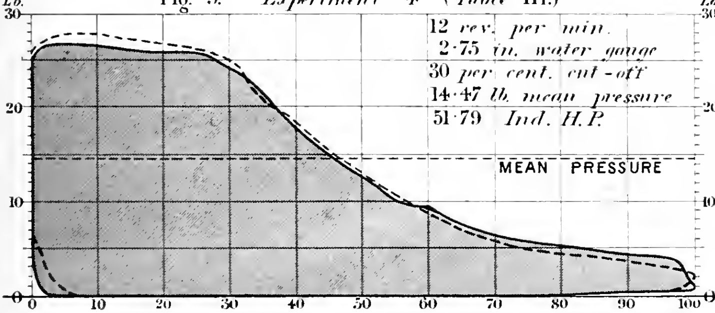


Fig. 10. *Experiment* 5 (*Table* III.)

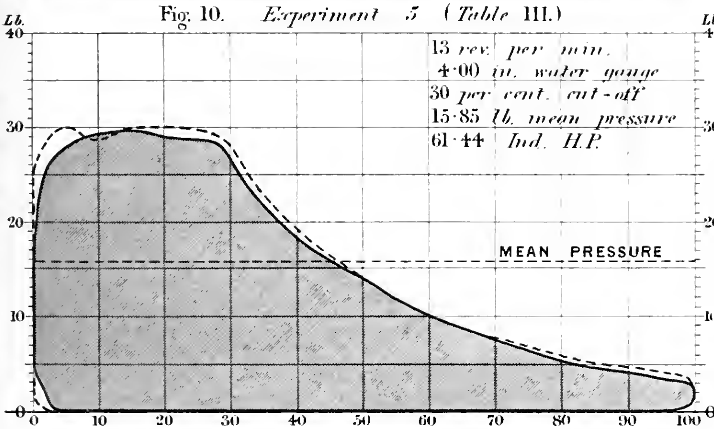
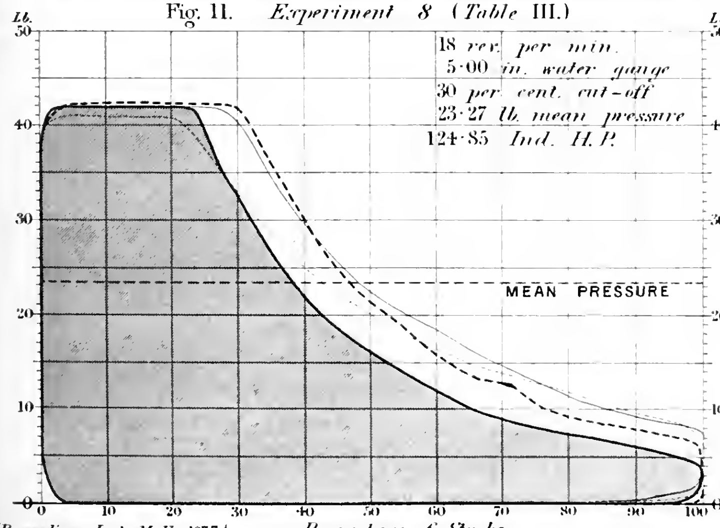


Fig. 11. *Experiment* 8 (*Table* III.)



Pressure above atmosphere, lb. per sq. in.

Percentage of Stroke.

(Proceedings Inst M. E. 1877.)

ROOTS' MINE VENTILATOR &C. *Plate 7.*

Indicator Diagrams from Engines driving Ventilator at Chilton Colliery.

2 *cylinders,* 28 *in. diam.,* 4 *ft. stroke.*

Fig: 12. *Experiment 10* (*Table* III.)

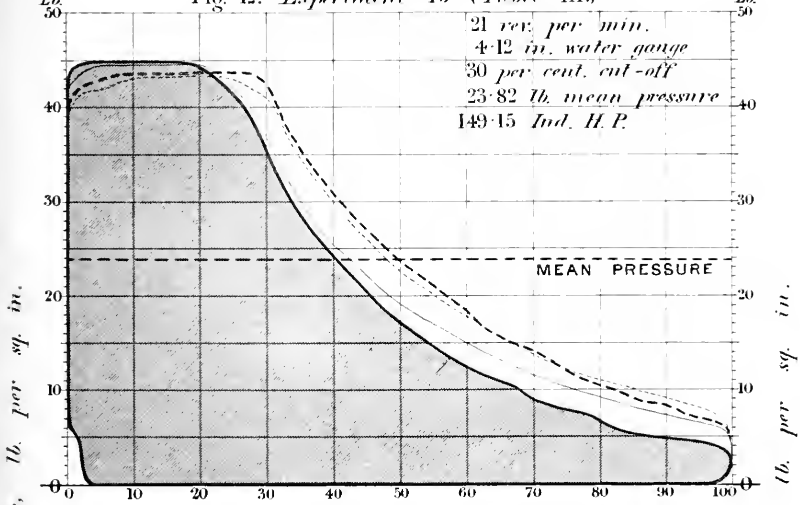


Fig: 13. *Experiment 15* (*Table* III.)

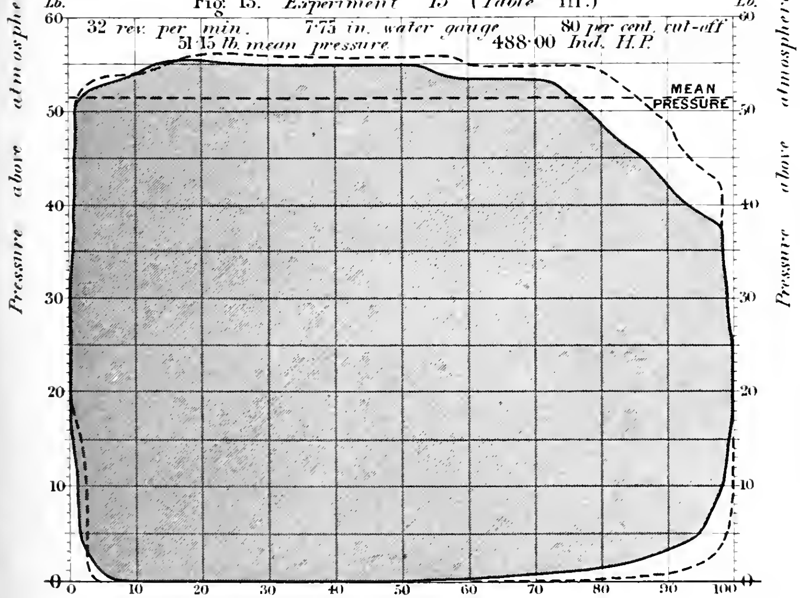
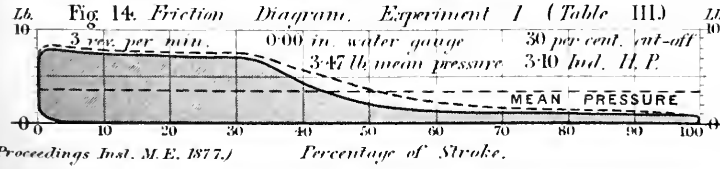


Fig 14. *Friction Diagram. Experiment 1* (*Table* III.)



(Proceedings Inst. M.E. 1877.) *Percentage of Stroke.*

ROOTS' MINE VENTILATOR &C.

Special Pressure Blower.

Fig. 15. *Transverse Section.*

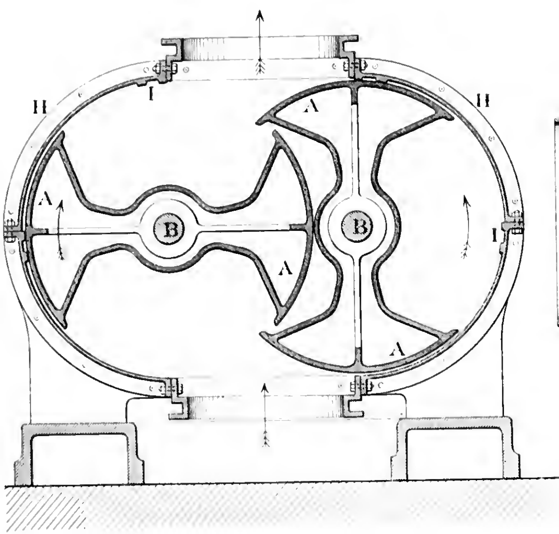
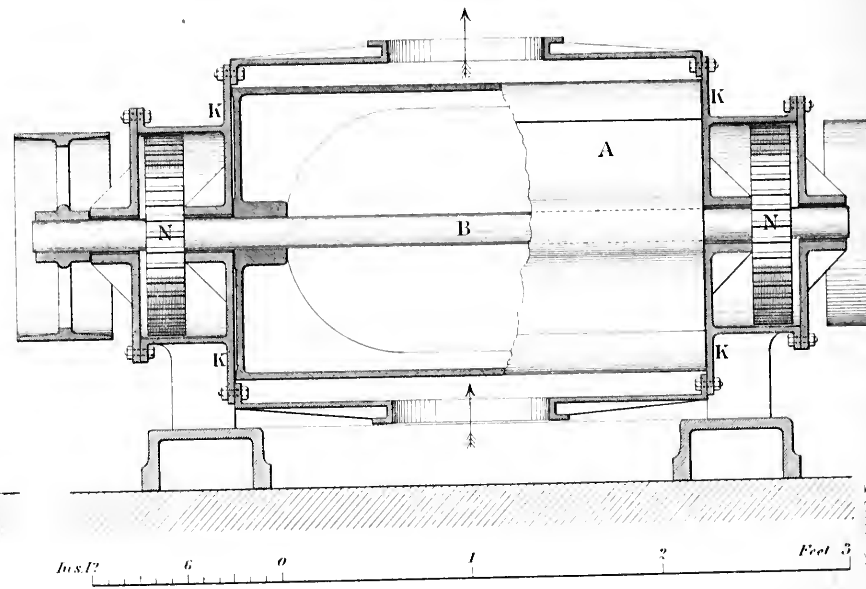


Fig. 16. *Longitudinal Section.*



(Proceedings Inst. M. E. 1877.)

Scale 1/12th

Plate 8.

ROOTS' MINE VENTILATOR &C.

Blower attached to Portable Forge.

Fig. 17. *Elevation.*

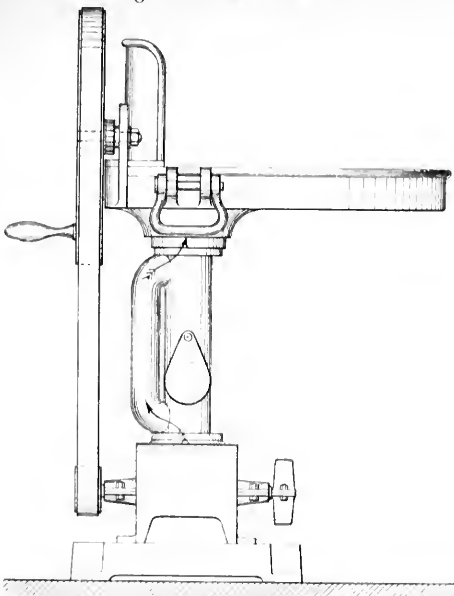


Fig. 18. *Section.*

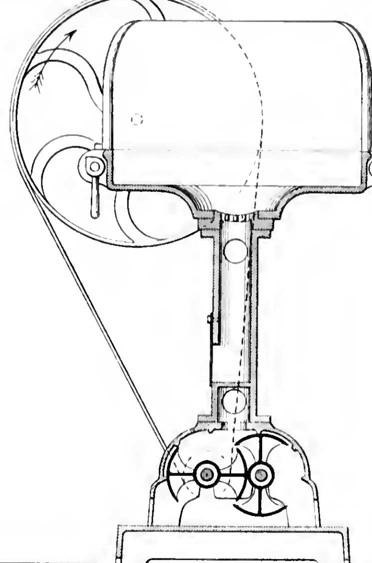
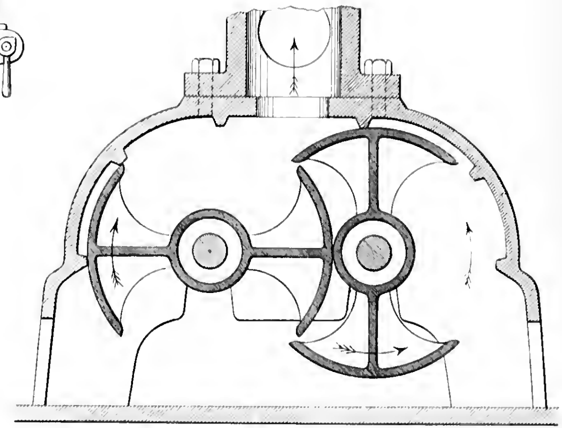


Fig. 19.

Transverse Section of Blower, enlarged.



Scale $1/4^{th}$

Scale $1/12^{th}$ Ins. 12 6 0 1 2 Feet.

(*Proceedings Inst. M.E. 1877.*)

Plate 9.

ROOTS' MINE VENTILATOR &C.

Blower for Cupolas and Smiths' Fires.

Fig. 20. *Transverse Section.*

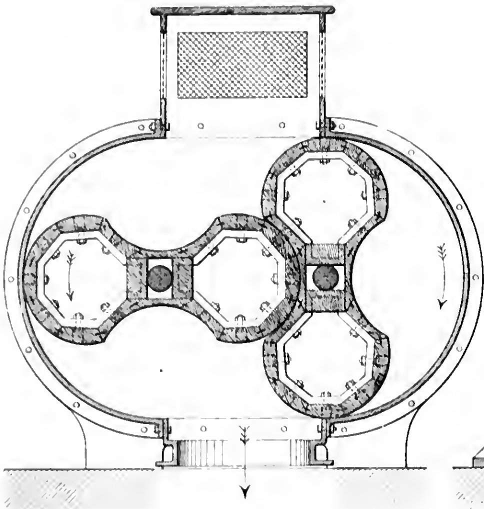
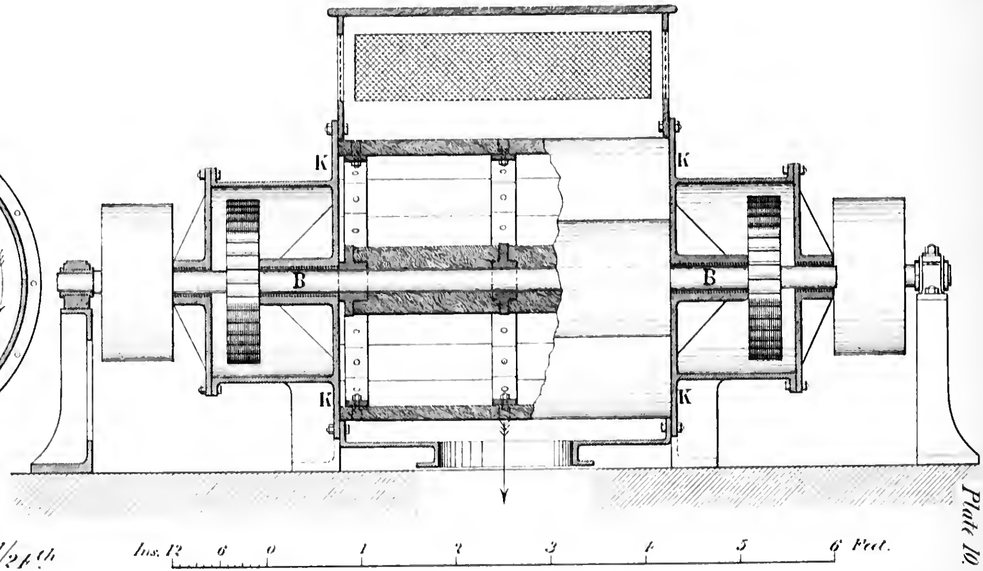


Fig. 21. *Longitudinal Section.*



(Proceedings Inst. M.E. 1877)

Scale 1/24th

Plate 10.

ROOTS' MINE VENTILATOR &C.

Combined Engine and Blower.

Fig: 22.

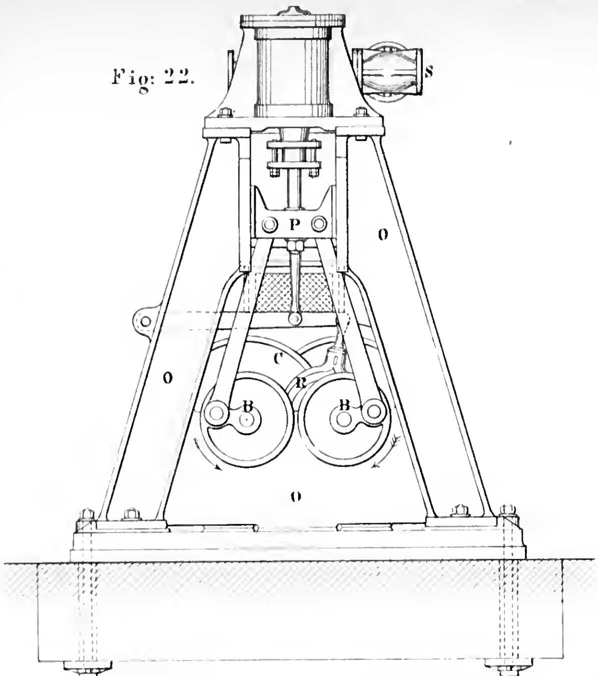
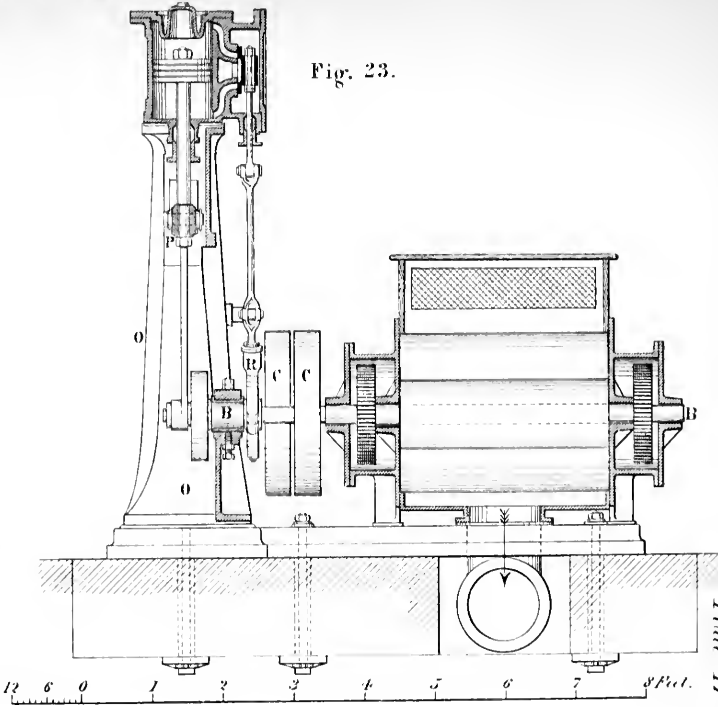


Fig. 23.



(Proceedings Inst. M.E. 1877.)

Scale 1/30th.

Plate 11

ROOTS' MINE VENTILATOR &c.

Blower and Exhauster for Chemical Works.

Fig: 24.

Transverse Section.

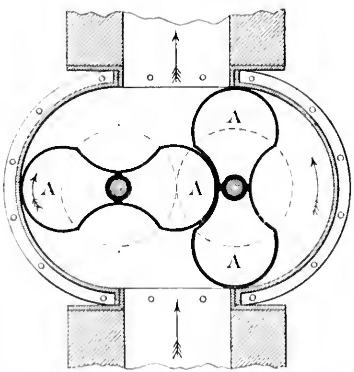


Fig: 25. *Plan.*

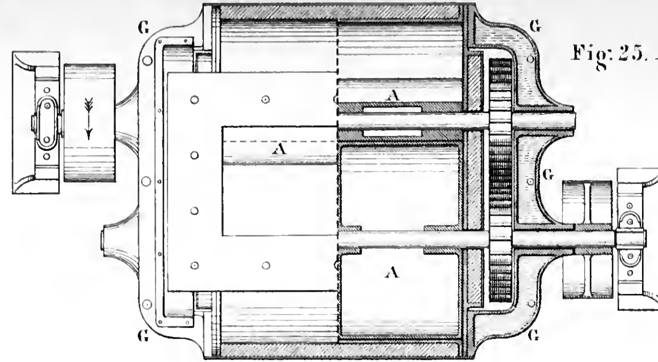
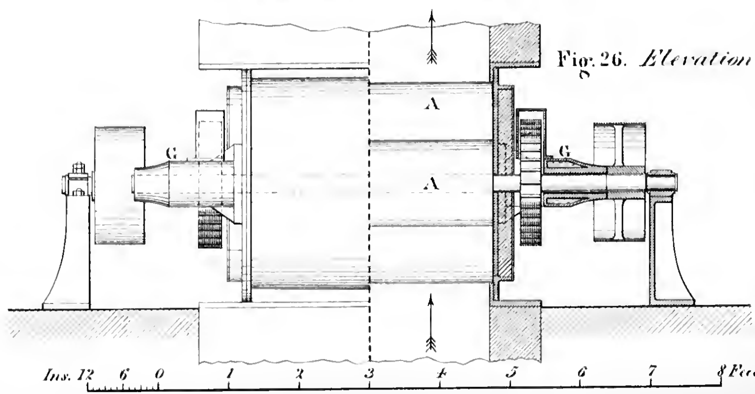


Fig: 26. *Elevation.*



(Proceedings Inst. M.E. 1877.)

Scale 1/30th.

Plate 12.

ROOTS' MINE VENTILATOR &C.

Gas Exhauster.

Fig. 27. *Transverse Section.*

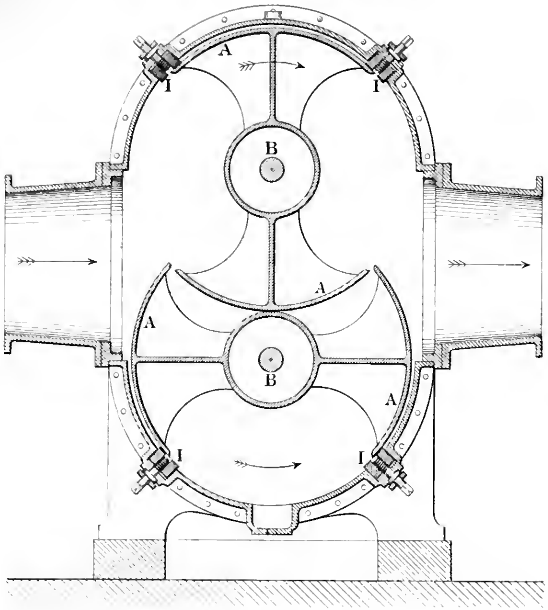
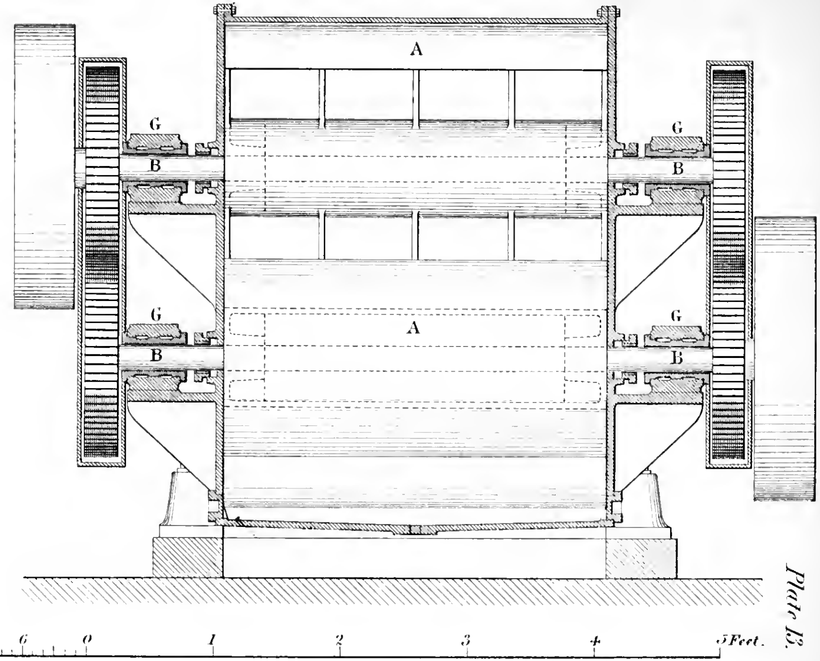


Fig. 28. *Longitudinal Section.*



(Proceedings Inst. M. E. 1877.)

Scale 1/18th.

Plate 13.

ROOTS' MINE VENTILATOR &C.

Forms of Rotary Pistons.

Fig: 29. *Roots' Blower.*

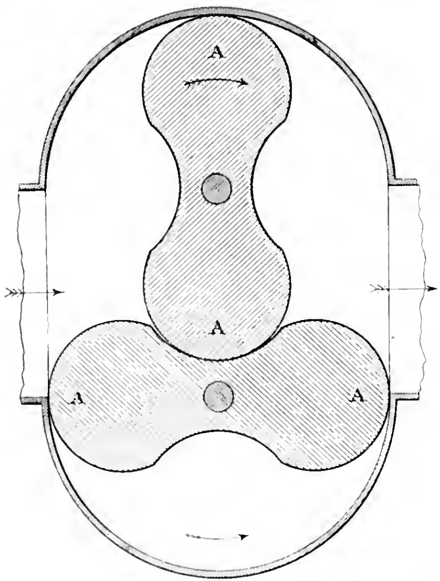


Fig. 30. *Jones' Gas Exhauster.*

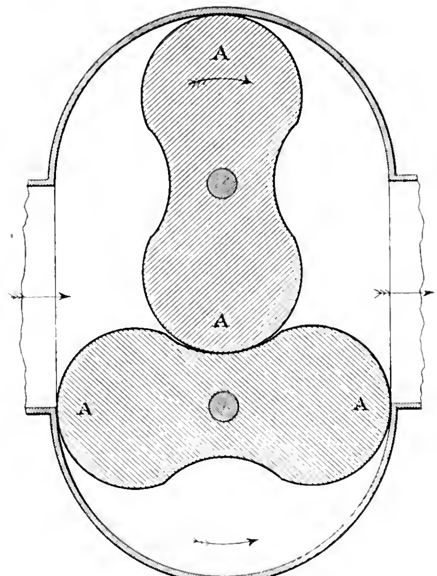
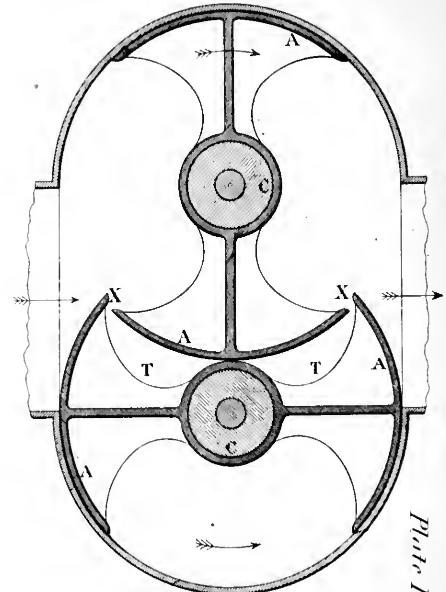


Fig: 31. *Roots' Gas Exhauster.*

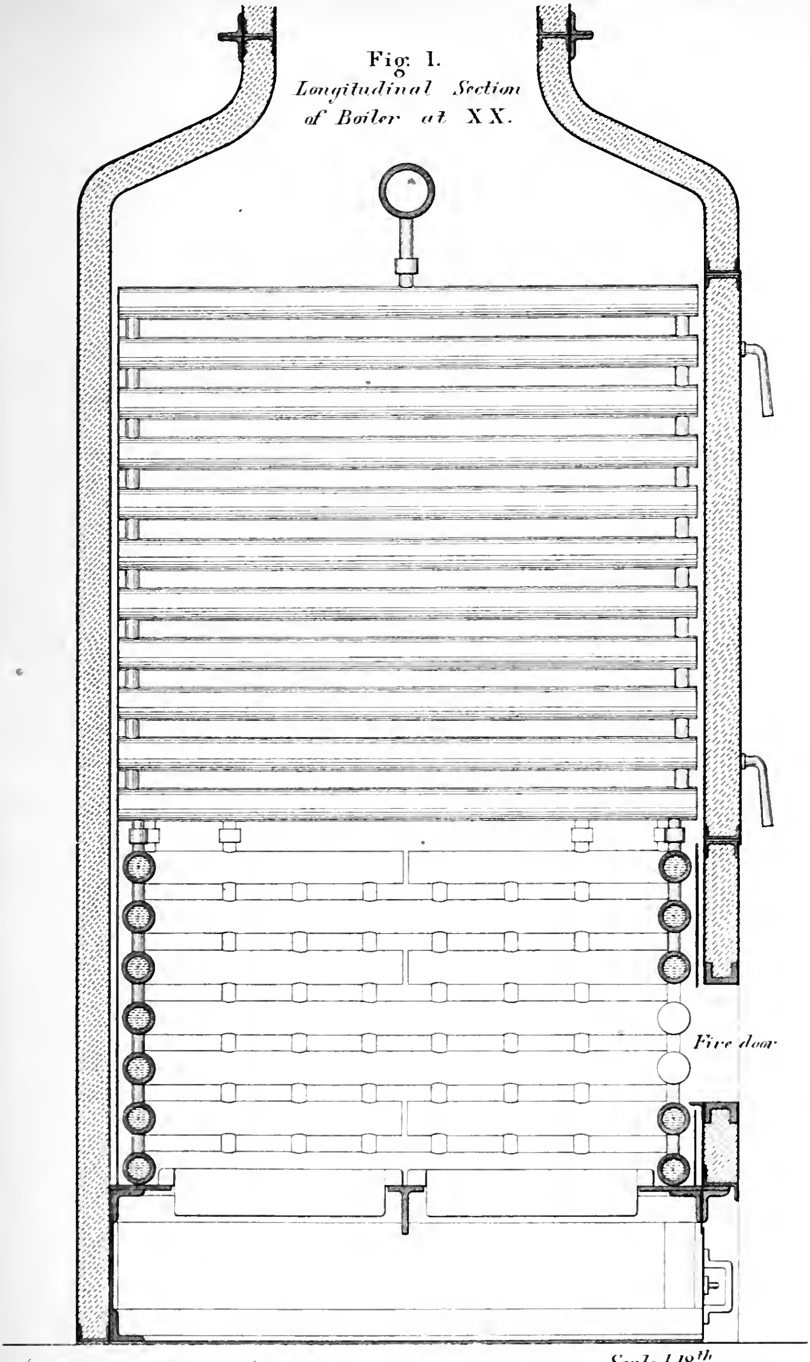


(Proceedings Inst. M.E. 1877)

Scale 1/16th

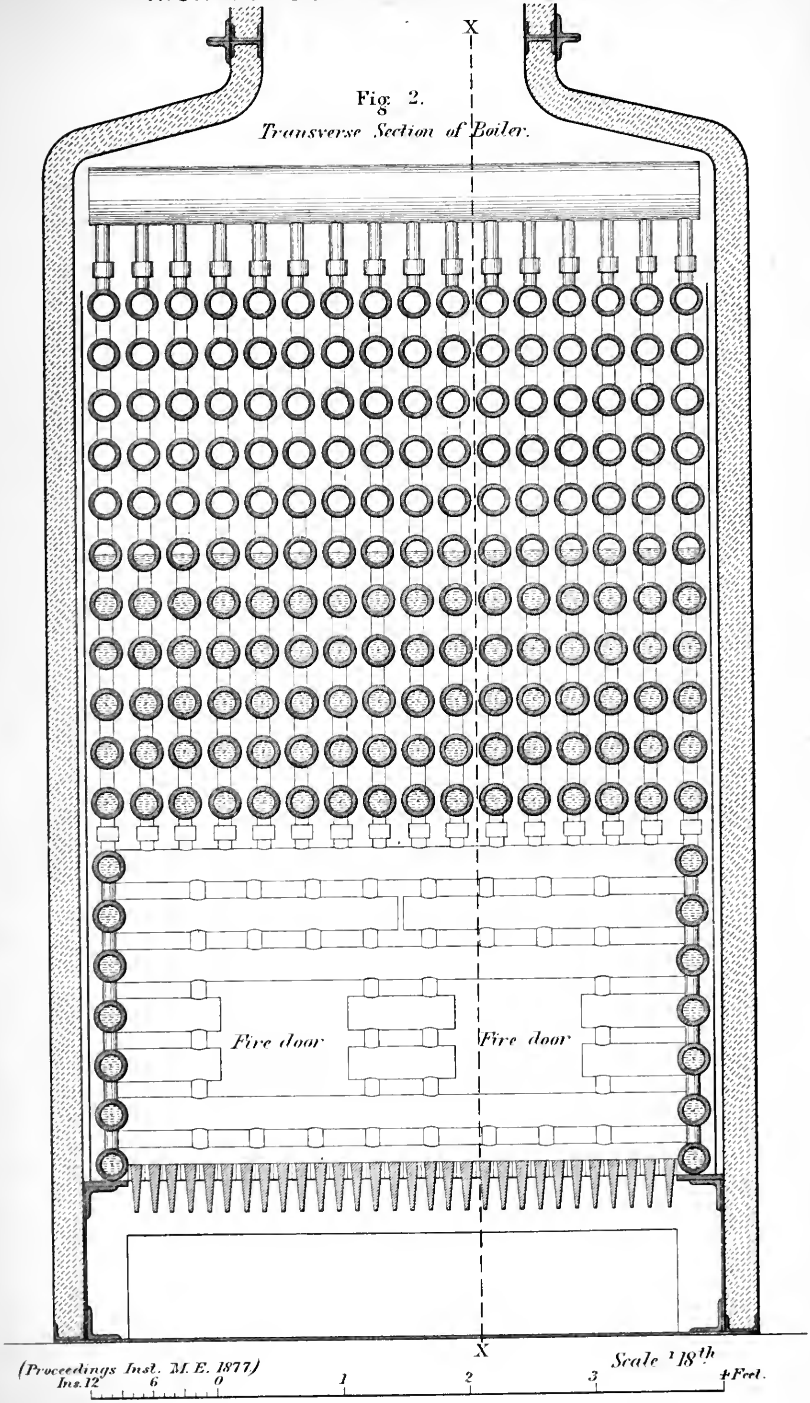
Plate 14.

Fig: 1.
Longitudinal Section of Boiler at XX.



Scale 1/18th

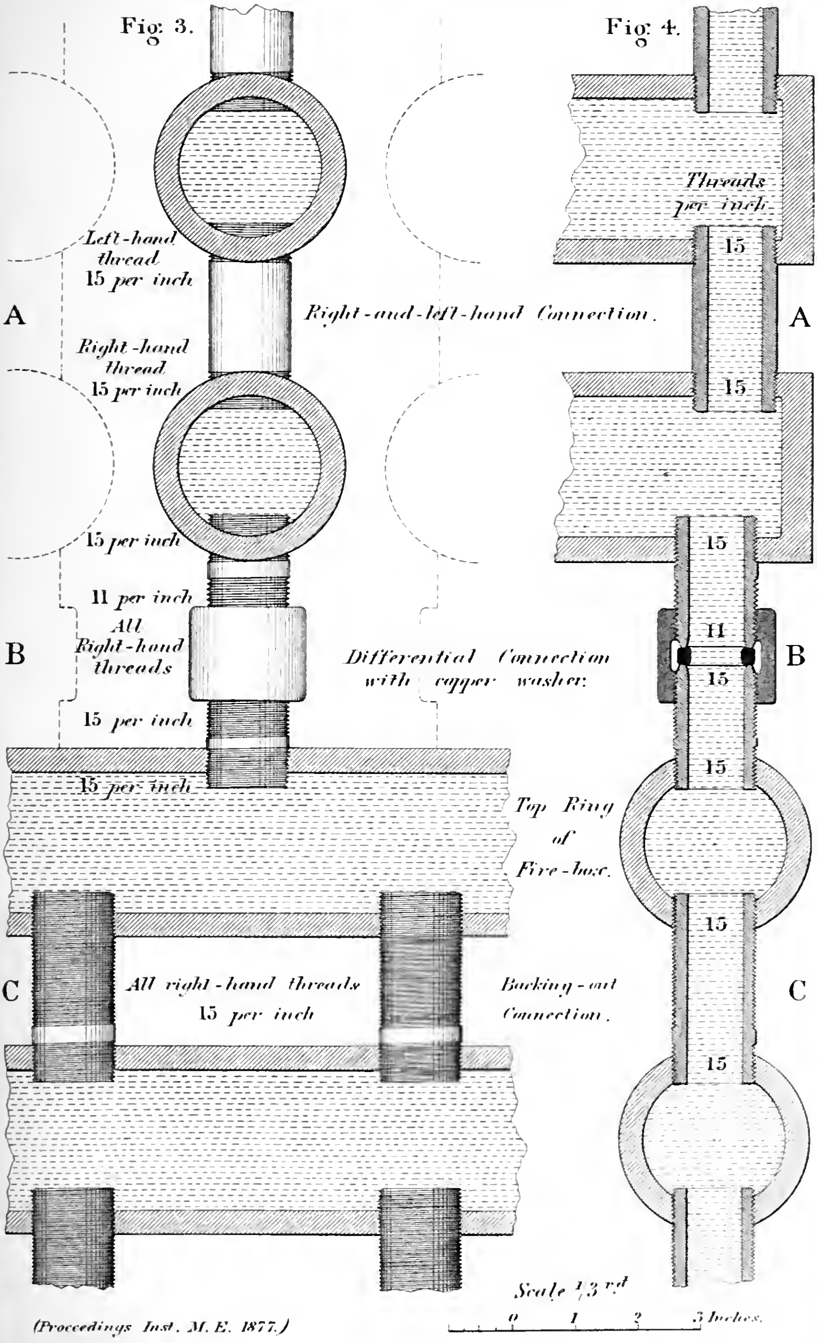
(Proceedings Inst. M. E. 1877.)



(Proceedings Inst. M. E. 1877)

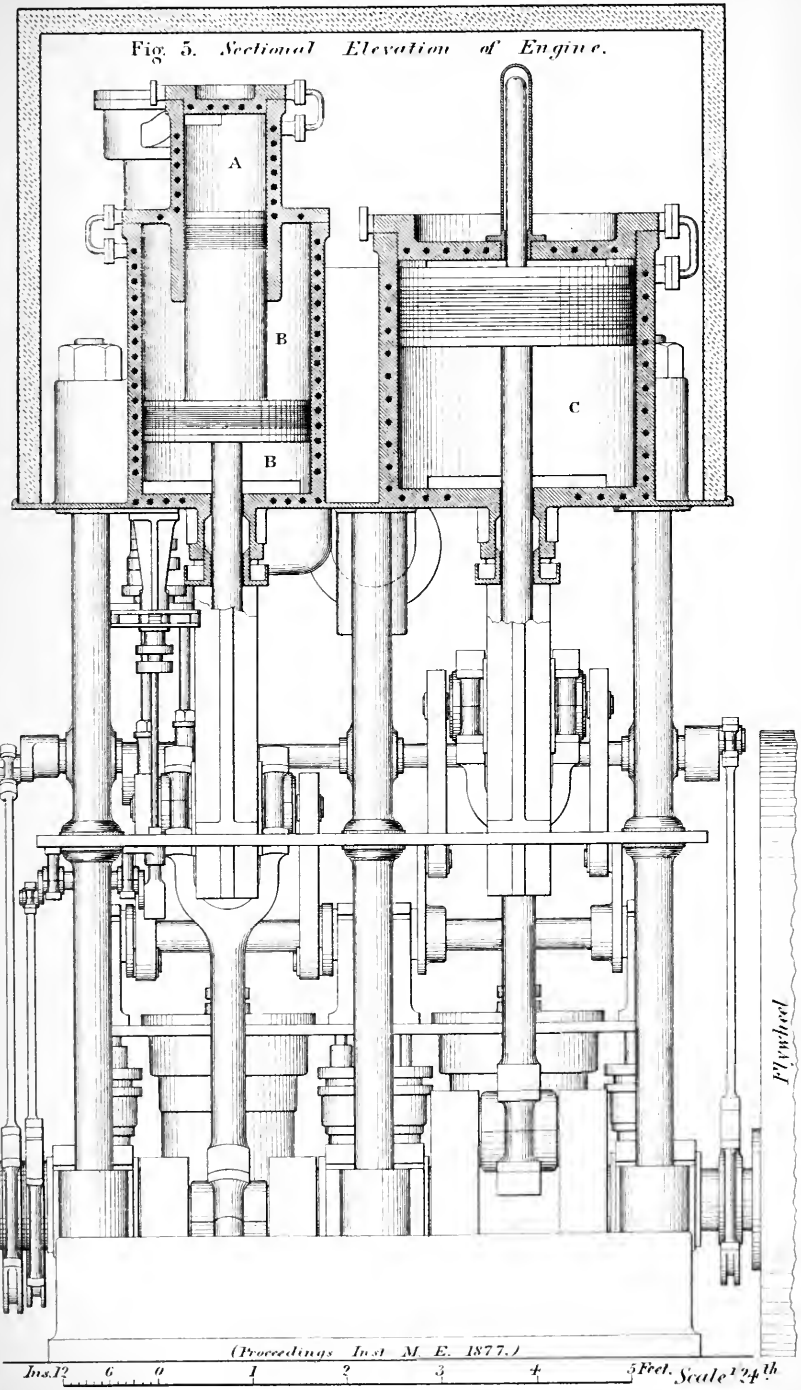
HIGH-PRESSURE BOILER AND ENGINE. *Plate 17.*

Boiler Tubes and Connections.



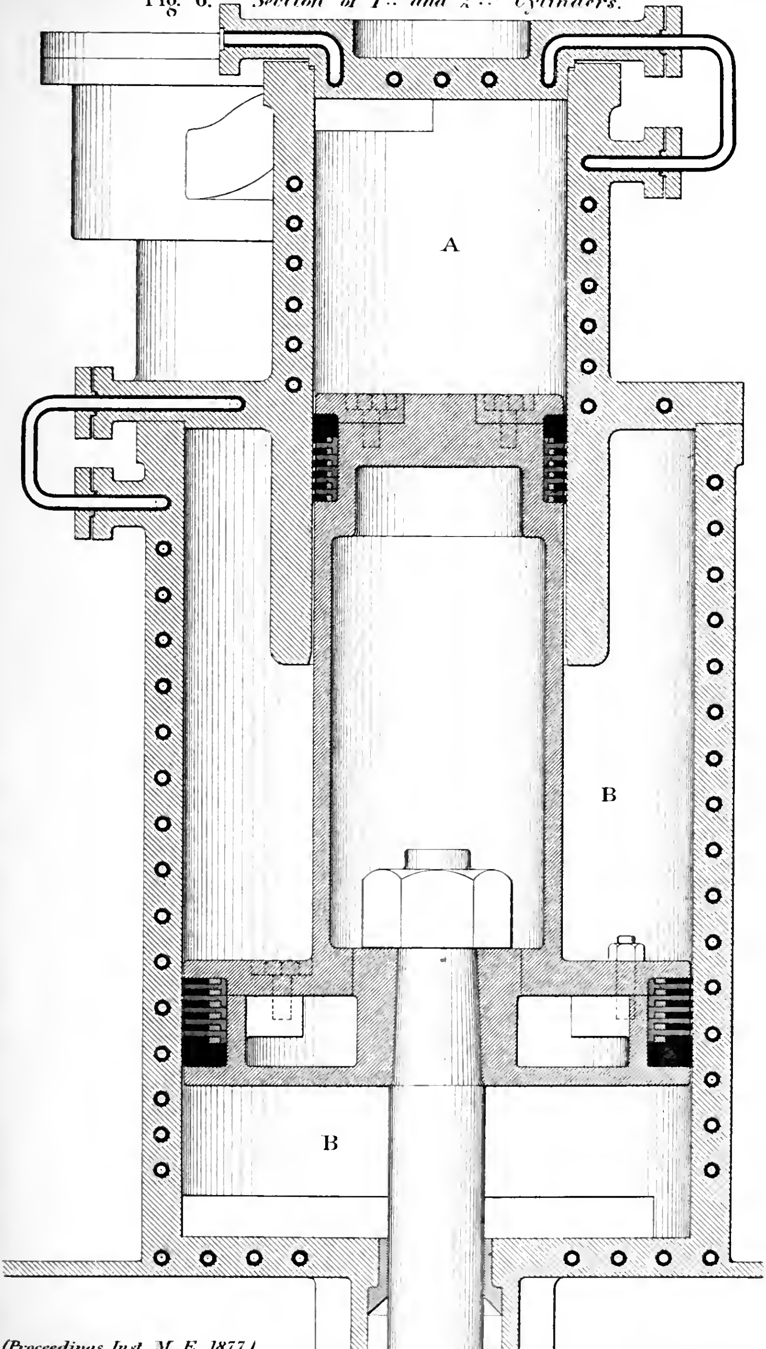
(Proceedings Inst. M. E. 1877.)

Fig. 5. *Sectional Elevation of Engine.*



HIGH-PRESSURE BOILER AND ENGINE. *Plate 19.*

Fig. 6. *Section of 1st and 2nd Cylinders.*



(Proceedings Inst. M. E. 1877.)

Ins. 12 6 0 *1 Foot.* *Scale 1/8th*

HIGH-PRESSURE BOILER AND ENGINE.

Fig. 7. *Surface Condenser.*

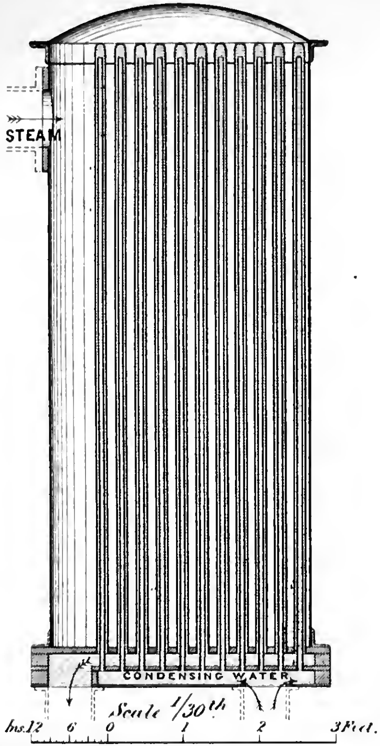


Fig. 8. *Detail of Tubes in Surface Condenser.*

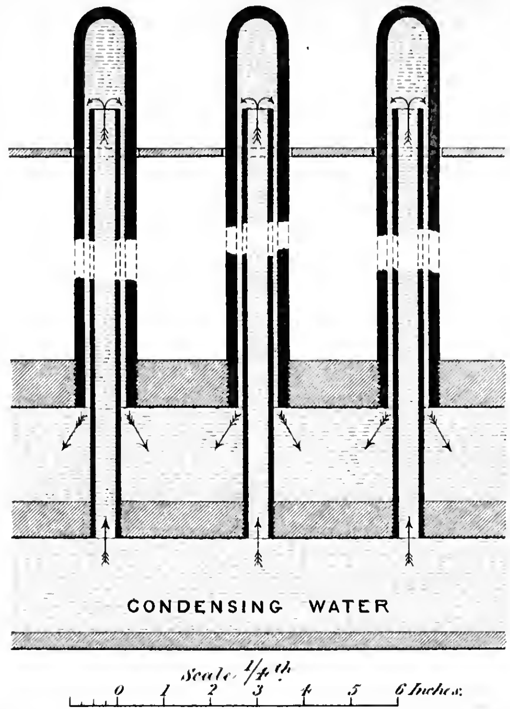
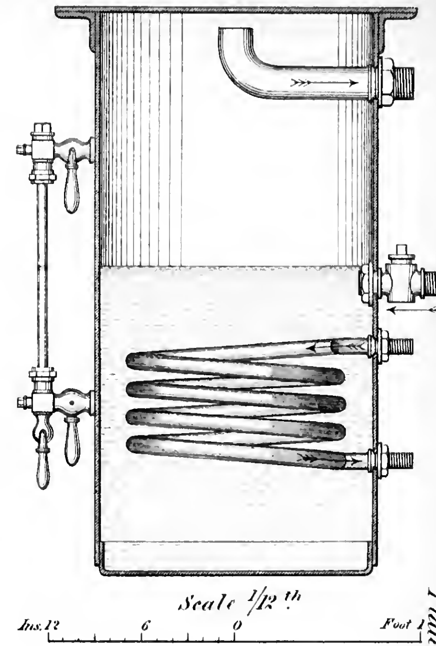


Fig. 9. *Still.*



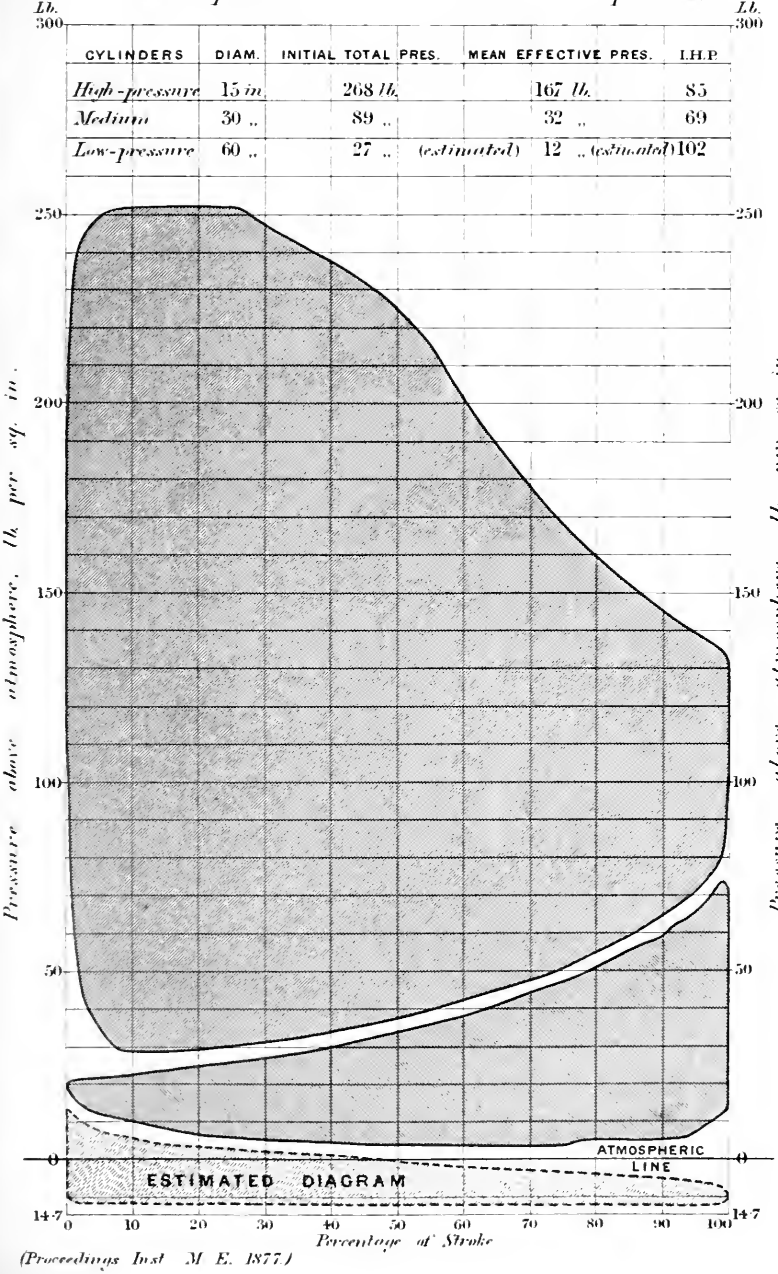
(*Proceedings Inst. M.E. 1877.*)

Plate 20.

Fig. 10. *Indicator Diagrams from Engine of "Filga."*

Rev. 98 *per min.* *Steam* 300 *lb. pressure.*

CYLINDERS	DIAM.	INITIAL TOTAL PRES.	MEAN EFFECTIVE PRES.	I.H.P.
High-pressure	15 *in*	268 *lb.*	167 *lb.*	85
Medium	30 ,,	89 ,,	32 ,,	69
Low-pressure	60 ,,	27 ,, *(estimated)*	12 ,, *(estimated)*	102



(Proceedings Inst. M. E. 1877.)

PROCEEDINGS.

July 1877.

The Summer Meeting of the Members was held in the Assembly Room, Grand Hotel, Bristol, on Tuesday, 24th July, 1877; Thomas Hawksley, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

MEMBERS.

James Astbury,	Birmingham.
Massey Bromley,	London.
Angus Campbell,	Roorkee, India.
William Carter,	Birmingham.
Frederick Edwards,	London.
Thomas Mark Elliott,	Fence Houses.
Daniel Walker Forbes,	London.
William Foulis,	Glasgow.
Robert Goodbody,	Clara, Ireland.
Wallis Rivers Goulty,	Manchester.
Robert Grundy,	Wigan.
Hermann Ludwig Lange,	Manchester.
John A. MacLellan,	Glasgow.
Vitale Domenico de Michele,	London.
Henry Sherley Price,	Manchester.
Edward Rutter,	London.
William Turner Simonds,	Boston.
Alexander Stewart,	Bradford.
David Walker,	London.

STUART CRAWFORD WARDELL, ...	Alfreton.
CHARLES ROBERT WESTERN, ...	London.

ASSOCIATE.

FREDERICK RENDER, ...	Manchester.

The PRESIDENT then delivered the following Address:—

ADDRESS OF THE PRESIDENT.

Gentlemen,

I am happy to inform you that the business to be transacted at the present Meeting is so considerable that my duties will be best performed by occupying, in my own person, as little of your time as the due fulfilment of my obligations as your President for the time being will permit. The Papers to be read and discussed are many, the places and objects of interest to be visited are numerous, and the hospitalities with which the ancient City of Bristol welcomes your advent are more than abounding. To the Mayor of Bristol, to the Master of the Society of Merchant Venturers, and to the Chairman and Officers of the Great Western Railway Company, we are especially indebted for the distinguished manner in which they are pleased to receive and entertain us, and for the unlimited trouble they are taking to render our visit as agreeable as it will certainly be useful and noteworthy. Nor must I omit to remark, that the principal local companies and manufacturers have freely and frankly opened their establishments for our inspection, and have most obligingly expressed their willingness to afford us all the facilities in their power. Neither must I forget to express my admiration of the able manner in which your Local Secretary, Mr. Wilson, has fulfilled the onerous obligations he so cheerfully accepted on our behalf, nor fail to acknowledge, with my warmest thanks, the unremitting exertions to which we are indebted in no inconsiderable degree for the well-assured success of our present gathering. The Programme of the Proceedings issued by our Secretary will, however, fully inform you of the occupations to which our four days of intermixed labours and festivities are to be devoted. To that document I therefore refer you.

It is necessary to say a few words respecting the present altered position of the Institution and its future prospects. You are all aware that the Institution of Mechanical Engineers has exchanged its Provincial for a Metropolitan habitat; but it may not be known to you that it is already domiciled in Victoria Street, Westminster, where it is in possession of handsome apartments excellently adapted for the transaction of the business of the Society, and for the useful accommodation of its members. There are five good rooms on the ground floor, besides two other dry and well-lighted rooms on the basement suitable for the storage of the Society's Maps, Drawings, and Publications. The principal rooms are intended to be devoted to the purposes of—

1. A Members' Reading and Correspondence Room.
2. A Library.
3. A Secretary's Room, to be used also as a Council Room.
4. A Clerks' or Sub-Secretaries' Office; and
5. A Drawing Office.

And it is believed that the establishment, thus arranged and properly organized, will become extremely serviceable to Foreigners and Colonists who, having business to transact in this country in relation to matters connected with Mechanical Engineering, have hitherto had no authenticated place of reference for such advice and information as our future Officers will henceforth be readily able to afford. It is also intended to provide, in addition to a Library of Standard Works of recognized professional merit, such Books of Reference, pertinent Periodicals, Maps, and Commercial Returns, as may be found to be the best calculated to promote the interests and suit the convenience of the Members of all classes.

During the brief period which has elapsed since the Members resolved to remove the Institution to London, the Council and their Committee, assisted by their Officers, have loyally and heartily endeavoured to accomplish the ends the Society had in view; and I can testify, from personal observation, that to the Committee generally, and to two of them, Mr. Cowper and Mr. Easton in particular, we are all very much indebted for the excellent results already attained.

It must not however be assumed that these results have been arrived at without some countervailing disadvantages; amongst others we lose the long experience and valued services of our esteemed Secretary, Mr. Marshall, whose name has, for nearly thirty years, been identified with the public and private interests of this Institution; services which well deserve the recognition and reward which it is the intention of the Council, with your approval, to bestow upon them. We also necessarily suffer a somewhat heavy augmentation of our disbursements for rent and other establishment expenses. Nevertheless, I am able to congratulate the Institution, not only because of the benefits it will derive from becoming located in the metropolis of the world, but also because we shall, as I fully believe, be enabled to claim a financial success by making both ends meet without taxing the Members or encroaching (except perhaps for the expenses of removal) upon our now very considerable accumulated fund.

These important changes in your circumstances as a Society have occurred during the period in which I have had the honour to be your President; and as they will very much affect the future position of the Institution, I hope you will not consider it out of place if I venture to address to you a few precautionary observations.

The occupations of a mechanical engineer are, as you well know, commonly of a very mixed character; professional as regards advice and design, commercial as regards manufacture and remuneration. The existence of competitions in business and of trade jealousies amongst yourselves is therefore inevitable. You would be more than human if your susceptibilities were not frequently awakened, and often even rudely awakened, by the incidents and accidents of your daily life and avocations. Your Institution will therefore flourish or languish just as you are careful or careless to prevent suspicions and causes for suspicions attaching to the conduct of your Officers in their relations to the Members. I have already intimated my opinion of the benefits the Institution may, irrespective of its scientific and practical character, be able to confer otherwise than directly upon its Members; but in order to effectuate this object for the general advantage of the Society, there must be a concurrence of unbiassed feeling and generous sentiment on the part of both Members and Officers. The

Officers on the one hand must be wholly detached from and unconnected with trade alliances in every form; whilst on the other hand the Members must, as a point of scrupulous honour, avoid all inducements to breaches of that good faith and impartial action which it will be the duty, as I hope it will be the pleasure and the disposition, of the Officers to manifest to the Members.

It was my desire and design to have recalled to your attention the chief improvements in practical mechanics and the cognate arts which have occurred in the last twelve or eighteen months; but, on reviewing this "recent past," I am not surprised to find that the coincident period of commercial depression has also been a period of marked inventive inactivity. It is true I might have discoursed on the Telephone, the Electric Candle, the Ortheoscope or "Light Mill," and some other recent developments of physical and chemical phenomena; but, however interesting or amusing the descriptions might be made, these and the like inventions and discoveries did not appear to me to be sufficiently connected with our own pursuits to form fitting subjects for discussion on the present occasion. There is however one exception. Earth and air are filled with wars and rumours of wars; and accordingly men's minds are occupied to an absorbing, if not to a ridiculous, extent in devising means for the more ready and comprehensive destruction of life and property. Believing as I do, and as all history teaches, that the combative tendencies of mankind are irrepressible, and that war, with all its horrors, is, however unhappily, an inevitable characteristic of humanity—a characteristic not amenable to the salutary influences of civilization, or of religion, or even to the moral certainty of absolute annihilation—for when were the dogs of war so often let loose, or let loose with such fatal effects, as they have been, notwithstanding our higher civilization and improved religious instincts, within the last quarter of a century?—believing, I repeat, that war is an inevitable calamity, and being also of opinion that this nation must, sooner or later, be drawn into what may easily become a widening conflict, it is surely the pre-eminent duty of all good citizens to look well to the care and protection of their homes, their hearths, and their means of

subsistence. And how, let me ask my countrymen, are these supreme objects of our solicitude to be assured? Not, as in the olden times, by the personal prowess of a stalwart peasantry; not by bow and arrow, sword and battle-axe; not even by gun and bayonet, but by vast and complicated machines, manœuvred by mechanism, to which human intelligence adds little more than their fatal direction—machines which other nations possess as well as ourselves, and in greater abundance, and to the possession of which we have, however illogically, been ever willing to lend them a helping and contributing hand.

Now, seeing that we English people "stand so thick on the ground" that we are obliged to import one-half of our food from abroad (a matter in regard to which we are differently and distinguishably circumstanced from all other peoples)—from countries, too, with which we may cease to be in amity, and across seas upon which an enemy's ship may triumphantly float—it is surely a paramount duty of our Government to adopt such timely measures as will secure to us the paths of the ocean for our food inwards, and for our manufactures, wherewith to pay for our food, outwards. And how? By ceasing to build in their own dockyards and arm in their own arsenals those enormous and unwieldy floating castles—castles, I think, of display and despair—which can at best be in but very few places at once, which can safely approach but very few coasts, which can enter but very few rivers or harbours, and which can guard or convoy but a tithe of our merchantmen—the loss of one of which would, in men and treasure, be a disaster almost equivalent to the loss of one of our counties; and by invoking, whilst there is yet the useful and favourable opportunity, the aid of you, the mechanical engineers of England, in order to provide the nation with a competent fleet of light, and swift, and well-engined ships, equally capable of sailing or steaming to any or every quarter of the globe where their services may be found requisite, and which, by the exercise of a daring and hornet-like activity, would succeed in driving every enemy's ship from the face of the sea. Add to this that the Government would thus obtain the benefit of the mother wit and speedily-acquired experience of many master minds; that our work-

people would be thus afforded the fitting opportunity of becoming skilled in and accustomed to a nationally important class of construction; and that the taxes taken from the people for warlike purposes would be thus redistributed amongst them in the form best adapted to their wants and habits, that is to say, for the most part, in payment for their skill and labour.

I beg you will not fail to understand, that in making these observations I am governed by impressions of a patriotic character rather than of a bellicose order. I detest war in all its phases, but I prefer war to starvation. When the day comes, and it most undoubtedly will sooner or later arrive, we must either fight or famish—fight and conquer, if we are fully prepared; famish and succumb, if we are unprepared.

There is one other subject of a vast, direct, and immediate importance to all classes in this kingdom. We are at this time diminishing our wealth and the means of supporting our rapidly-increasing population by more than £100,000,000 per annum! And why? Simply because foreign nations will not voluntarily take such sufficient quantities of our goods as to enable us to liquidate our constantly-recurring indebtedness to them for the food we involuntarily require at their hands. Again let me ask, why? Simply because we do not manufacture cheaply enough, and, to some extent, well enough. For the third time let me ask, why? Simply because our labour is too dear—too dear in respect of price, too dear in respect of the quantity of work performed, and too dear in respect of the obstructions and restrictions which the modern workman thinks fit to place upon his employment and employer. In all these respects the English capitalist employer—the workman's best friend—is placed at a singular and often ruinous disadvantage when he is brought by the exigencies of his business into immediate competition with the foreign capitalist employer, who, although suffering to some extent from the operation of similar interferences, suffers from them in a much milder degree and to a much smaller extent. The causes of this immense loss to the country—a loss of such magnitude that it cannot be continued for many years without involving the nation in

ruin—are not difficult to discover or far to seek. We have passed through a period of unnatural and factitious prosperity. The capitalist has, unfortunately for himself and his country, in too rapid a manner, duplicated and reduplicated his wealth; whilst the working man observing this, and being misinstructed by his popular advisers—themselves utterly ignorant of the first principles of international political economy—has conceived and become thoroughly imbued with three transparently false notions.

First. That he is entitled to share in his employer's success in business.

Second. That he has a right, *in combination with others*, to exact conditions from and prescribe terms to his employer.

Third. That he has a right, *in combination with others*, to force his employer to yield to his exactions and prescriptions—exactions and prescriptions which concern not merely himself, but which are so exercised as to control the employer in regard to the manner in which he shall conduct his business, and even in respect of his relations to the general public at home and abroad.

Besides this the workman is induced, by popular misrepresentations, to believe that capital is rather his enemy than his friend, and that he has a perfect right, by unionistic efforts, to crush his employer's trade for union purposes, and so to destroy, in the result, the source of his own livelihood. And again, the working man has been and is still so mistaught as to have become firmly convinced that an increase of wages, however enforced, is necessarily a sound and permanent addition to his own means of living, in comfort or otherwise, and only too frequently "otherwise."

Owing to these patent mistakes, wages (but not the means of living) have, of late years, been unduly forced up in this Kingdom; whilst, on the other hand, production has been relatively as unduly forced down. Trades once monopolised by England, the whilome workshop of the World, have become wholly or partially settled elsewhere; whilst our own working people, still unshaken in their belief in the virtue of strikes, high wages, short hours, and workshop

restrictions, are only partially employed, and that too with the certainty staring them in the face that, unless they cease to conspire to make goods dear—the goods they buy as well as those they make—their opportunities of earning a comfortable livelihood must necessarily become from year to year fewer and fewer, till in the end, when we shall have lost the larger part of our foreign export trade, the struggle for existence will become most painfully and increasingly severe among them, and less and less capable of mitigation.

Much observation and a long experience have finally brought me to the conclusion that, if the trade of this country is to be saved, and if the British workman is to be secured of his industry and its well-merited fruits, the cost of all commodities, labour included, must be closely assimilated in this Kingdom to the cost of like commodities on the Continent of Europe and in America. May man and master speedily open their eyes to this already pressing necessity.

Mr. F. J. Bramwell, in moving a vote of thanks to the President for his address, observed that, like all documents emanating from him, it was of a highly suggestive and argumentative character. He was only sorry the President had found himself compelled to put before them that which he himself gave as so gloomy a statement; but although the address was not such a one as they had been in the habit of receiving in this Institution, there was no doubt whatever that it went to the root of the existence and the prosperity of the manufactures of this country; and mechanical engineers were of course highly interested in the progress of those manufactures. It was difficult to separate one section of the kingdom from another in respect to this address, because in truth it dealt almost with the existence of England as a nation—a nation compelled to import a very large percentage of its food, and compelled therefore to keep the seas open: it dealt with the means which the government took to

keep those seas open, and with the means by which, even if the seas were kept open, the food was to be paid for. He did not know that more serious and grave subjects could be brought before a meeting of reflecting men; therefore, whether they agreed with the President or not in all his views—and he did trust that they might conscientiously differ from him on some points, for if not, they were in a very bad case indeed—he was sure they would join in thanking him for having set them thinking upon matters so important as those with which his address had dealt.

The vote of thanks was carried by acclamation.

The following paper was then read :—

ON THE CONSTRUCTION OF SAFETY VALVES.

BY MR. JOHN C. WILSON, OF BRISTOL.

Attention has been called to this subject by the occurrence of deplorable results from explosions of steam boilers caused by defective construction and working of the Safety Valves; and the object of the present paper is to consider the past construction of safety valves,—to illustrate and describe those valves which have hitherto been in most common use,—to indicate the principles upon which safety valves should be constructed,—and to illustrate and describe a valve which, by combining those principles, has proved itself practically successful.

Of those safety valves which have hitherto been in most common use, Figs. 1 and 2, Plate 22, represent the ordinary safety valve, which until recent years may be said to have been the only one in common use. It is the most primitive conception of a safety valve; consisting of a seating, with a plain moveable valve resting upon it, and a lever with a weight or spring attached to the end to give the required load on the valve for the purpose of counteracting the pressure of the steam underneath it. Two forms of the moveable part of this valve are shown: namely Fig. 1, guided in the seating with three wings, and Fig. 2, with a central spindle.

In this construction of safety valve the following points may be noted:—

1st.—The seating is of brass, let into a cast-iron cover. As both metals are subject to the same temperature in the working of the boiler, the brass metal will expand twice as much as the cast-iron, and an undue compression and possible distortion of the brass seating will ensue.

2nd.—The moveable part of the valve being guided in its motion by the brass seating, if undue compression or distortion of the seating

should take place, this part of the valve—the critical part of it—may be either irregularly guided and therefore "jammed," or it may be "nipped" or held fast. It is clear, whatever the precise result may be, there is always in this construction a possibility of irregular agencies of this nature coming into play and disturbing the mechanical accuracy of the valve.

3rd.—When this valve rises, it is evident that it will cease to be subject to the same pressure as when it is closed; for the moment it rises, the mass of steam which had hitherto been quietly pressing against its under surface will commence to flow in a direction at right angles to that surface, and diminished pressure against it must necessarily ensue. This is a radical defect in this safety valve, that while blowing off it is not subjected to the full pressure of steam within the boiler.

4th.—The load on the lever of this valve being capable of being easily tampered with, it cannot be considered a reliable index of the pressure of steam within the boiler.

5th.—When a spring instead of a weight is attached to the end of the lever, the increasing tension of the spring as the lever rises tends to put an increasing load upon the valve; and this, coupled with the diminished pressure on the valve after it rises, as above alluded to, causes the opening for the escape of steam to be greatly restricted, and consequently the pressure in the boiler to become increased.

As will be observed in the drawings, the lever is shown constructed with knife edges, or in steelyard fashion, instead of with joints and pins. The knife edges are a great improvement, as there is no liability in them to stick fast, while there is much greater accuracy of leverage, and much less friction. The strut being made as shown, namely in the form of a simple pin with rounded end, ensures the load being put evenly on the valve at whatever angle the lever may be standing.

In Fig. 3, Plate 22, is shown the ordinary dead-weight safety valve, hitherto used chiefly for marine purposes. Two descriptions of the moveable part of this valve are shown, namely at A, having a central spindle to guide that part in the seating, and at B, having

three wings. These forms of construction are subject to the same remarks as have been applied to the valves shown in Figs. 1 and 2. In this valve a dead weight W takes the place of the lever with its weight or spring in the ordinary valve, the advantage of this alteration being that the load on the valve cannot be so readily altered, and the load is applied direct; but this is manifestly a cumbrous valve, with the addition of another guiding point to the spindle; and in the case of its application to marine purposes the load on the valve must be altered as the weights are more or less inclined by the swinging of the vessel to and fro, or as the momentum of the dead weight may suddenly exert its force at the termination of each rising or falling motion of the vessel. It is necessary for a marine safety valve to have an escape steam pipe; and one point to be carefully attended to in regard to it is to arrange for the removal of any water that may tend to accumulate in the pipe, or in the casing round about the valve, for the momentum of a body of water accumulated there, when suddenly propelled forward by the steam escaping from the opened valve, has proved peculiarly destructive.

In Fig. 4, Plate 22, is shown the Cowburn dead-weight safety valve, its principal features being the suspension of the weights below the acting surface of the valve, instead of their being piled up above it as in the above-mentioned valve, thus lowering the centre of gravity of the load in relation to the acting surface of the valve, and rendering the action of the valve itself easier; also the moveable part of the valve has no wings or central pin to guide it in its seating, but is made convex, or the segment of a sphere, so as to swing easily over the seating. But after allowing for these improvements, this valve remains subject to nearly all the other defects of the ordinary dead-weight safety valve shown in Fig. 3.

In Fig. 5 is shown Naylor's improved safety valve, as designed for locomotive purposes. This invention was intended to correct one of the defects mentioned in describing the ordinary safety valve, namely to prevent the pressure of the steam whilst blowing off through the valve from rising beyond the limit to which the valve has been adjusted; especially in locomotive boilers, where the safety valves are pressed down by levers with spring balances at their

extremities, and the rising of the lever in blowing off causes a constantly increasing tension of the spring in the spring balance and consequent increased pressure upon the valve. It operates by causing the spring that presses upon the valve to act not through a constant lever, but through one which varies in its effective length; this variation being so arranged that as the valve rises the lever diminishes in length in the same proportion as the tension of the spring is increased. This valve is further intended to make it impossible for the engine driver to tamper with the spring so as to increase the pressure beyond the intended limit. It is undoubtedly an ingenious mechanical invention for accomplishing both of these objects, but it is cumbrous and expensive.

In Fig. 8, Plate 23, is exhibited Ramsbottom's mode of weighting safety valves, applied however to a new valve. This arrangement has been in extensive use, especially for locomotive purposes. The points to be noted in connection with it are—great simplicity, great absence of means of tampering with the load, convenient funnels for the escape of the steam, and a ready means of ascertaining by a touch of the lever if the valves are working freely. But this invention has not touched the cardinal defect of the ordinary safety valve, namely the reduction of pressure upon it after rising from its seat, and the consequent restriction of its opening and increased pressure of steam within the boiler.

From the above and other considerations the following principles regulating the construction of safety valves are deduced:—

1st.—It is evident that the seating and the valve should be made of the same metal, for they are required to fit each other at varying temperatures, and this can only be accomplished when the metals are alike. *Safety* being the first consideration in a safety valve, any other—such as a small economy—which may tend to interfere with the certainty of the valve's action, ought to be disallowed.

2nd.—The seating should never be made in the form of a brass bush inserted into a cast-iron cover, for the important reason of the difference of expansion of the two metals, as previously named.

3rd.—The valve should be so constructed that the *full* pressure of the steam within the boiler is always operating on it, so as to cause it to rise to the utmost possible extent when the steam is being generated freely.

4th.—The bearing surface of the valve should form the smallest possible percentage of its area; and the valve should be at all times guided evenly upon its seat. The bearing surface should be of a conical form for the highest pressures, that being the most easily kept tight.

5th.—While the valve itself should be quite open and free for inspection and trial to ascertain if it is working properly, means should be adopted for preventing its load from being easily tampered with.

6th.—In constructing the lever form of valve, joints and pins should be discarded, and the steelyard fashion with knife edges should be substituted.

7th.—For marine purposes, the direct spring-loaded valve is to be preferred to the dead-weight; and the writer may here remark it is generally understood that this principle is now being fully adopted by the Board of Trade.

Having indicated the principles which ought to regulate the construction of safety valves, the writer will now proceed to illustrate and describe a valve which, by combining those principles, has proved itself practically successful.

In Plates 23 to 25 is shown a safety valve first invented by Professor J. Klotz of Prague, and since then improved and manufactured by the Avonside Engine Co., Bristol. It consists, as will be observed in the section, Fig. 13, first, of a seating C that is not used to contain the moveable part of the valve, as in the ordinary safety valve, but merely to fix the valve in its place, and to form the base of its superstructure, and to supply a passage for the escaping steam. Secondly, of a hollow cylindrical part D, which is raised above this seating, and attached to it by feathers, and forms the guide to the moveable part of the valve. Thirdly, of a moveable part E, which instead of fitting within the seating C, as in the ordinary safety

valve, fits outside of this cylindrical part D. The cylindrical part is closed in the centre to all except a pipe F ; also the moveable part E is closed at the top as usual, and there receives its load. Here is a radical departure from all previous constructions of safety valves ; and the moveable part E is not actuated by the escaping steam, but by the full pressure of steam within the boiler, specially conveyed to it by means of the pipe F screwed into the solid centre of the cylindrical part D. Thus the first three and the most important principles of construction which have been indicated are embodied in this valve.

The illustration in Figs. 6 and 7 shows this valve as arranged with a lever and weight for stationary boiler purposes ; that in Fig. 8 with Ramsbottom's lever and spring for locomotive purposes. A specimen valve is exhibited on the table.

For marine purposes, a new adaptation of this valve is shown in Plate 24. The springs, as will be observed, are not subject to the action of the escaping steam ; and means of easing the valve can be readily provided.

For locomotive purposes, the most improved adaptation of this valve is shown in Fig. 12, Plate 25 ; and a specimen pair of valves for a 16-inch cylinder locomotive engine is exhibited.

Professor Klotz states that experiments were made on a boiler having 272 sq. ft. of heating surface, with a $3\frac{1}{4}$ in. Klotz safety valve, so loaded as to allow the steam to escape at a pressure of 70 lb. per sq. in. ; and that when the valve had been shut the steam began to escape at $69\frac{1}{2}$ lb., and it took 44 minutes of continued forced firing of the boiler, during which time the steam escaped violently from the safety valve, before the pressure was got up to 76 lb., after which it could not be made to rise any higher. Another ordinary safety valve of $2\frac{7}{8}$ in. diameter upon the same boiler was then allowed to be the only escape for the steam ; it was loaded in the same way, steam began to escape at $68\frac{1}{2}$ lb., but after moderate firing during 7 minutes the steam rose to $76\frac{1}{2}$ lb., after which it rose so rapidly that to prevent danger the Klotz valve was put in operation. The correctness of the above statement has been tested at the Avonside Engine Works by a trial with two engines in the erecting shop. The two engines were similar, and had exactly the same Klotz safety valves, only the

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pressure pipes were taken away from one of them so as to change the action of the Klotz valve into that of an ordinary safety valve. When steam was up, and the firing continued, there was a very marked difference in the behaviour of the two boilers; the pressure in the one with the Klotz valve could not be increased more than a few lbs., whereas in the other the steam continued to rise until it was found advisable to stop the trial.

These valves have been largely applied by the Avonside Engine Co. to locomotive boilers; and Messrs. J. and E. Wood of Bolton have also applied them, as a precaution, to the intermediate receivers between the cylinders of compound engines.

In conclusion the writer would remark that he believes this to be a most important subject for discussion at this Institution in the interests of the public safety.

Mr. Wilson exhibited specimens of the Klotz safety valves, as applied to stationary, locomotive, and marine boilers.

Mr. F. W. Webb observed that in the construction shown of the locomotive safety valve, having the valve enclosed within a brass casing made in two separate portions, if the upper portion of the casing were sufficiently loose for a man to lift it up against the top lever, then by putting a wedge between the two portions of the casing the valve could be hermetically sealed. Having had to deal with a large number of the Ramsbottom safety valves, he had seen the disadvantages of the men being able to tamper with them, as had been done by putting a clip on two or three coils of the spring; and he had endeavoured to get over the difficulty by putting the whole in a close box, so that no one could get at the spring at all. With regard to the valve now described, it appeared to him that, if the boiler primed or stood a long while without blowing off, the two surfaces of the valve and the seating which were in contact inside

might be liable to corrode; and if any dirt or mud were to get in between them from the boiler it might set the valve fast, and so deceive a person as to what the real pressure in the boiler was. He should be glad to know how it was intended to get over these apparent objections in the valve.

Mr. LEWIS OLRICK thought the valve now described could hardly be regarded as "a radical departure from all previous constructions of safety valves," because a valve very similar to this had been invented at least 14 years ago by Mr. Bodmer, who however went a little too far. Instead of making, as in the Klotz valve, a very loose joint between the valve and its seating, so that there was no actual contact between the internal circumference of the valve and the external circumference of the cylindrical seating inside the valve, he made the valve a piston working in a cylinder, and the consequence of its acting as a piston was that there was a certain amount of friction, which prevented the valve from working freely, and in practice it suffered from the very defect which had been pointed out by Mr. Webb; and he believed there were now very few valves in use of that description.

There was one point with regard to safety valves which he thought should be added to the recommendations given in the paper, namely, not to put too large valves upon boilers—rather to put two or three smaller valves on a boiler than one large valve containing the same total area. As an illustration, a safety valve of ten sq. in. area would be about $3\frac{5}{8}$ in. diameter, with a circumference of 11·38 in.; whereas with ten valves of one sq. in. area each—he did not recommend that number and size, but merely used an extreme illustration — the diameter of each would be $1\frac{1}{8}$ in., and the circumference 3·53 in.; consequently ten safety valves of one sq. in. area each would have a total circumference of 35·3 in., or more than three times the area of outlet with the same height of lift as compared with a single safety valve of ten sq. in. area.

With regard to Naylor's safety valve, this was generally admitted to be a very ingenious one, and he could not concur in the opinion expressed in the paper that it was cumbrous and expensive; comparing

it with the Ramsbottom safety valve, there was not sufficient difference he thought between the two to lead to one being called cumbrous as contrasted with the other. He had a favourable opinion of Naylor's safety valve, because of having had something to do with a valve similar to it, which was the joint invention of Mr. E. Field and himself, and was on the same principle as Naylor's. In the ordinary spring-balance valve, as pointed out in the paper, when the spring stretched an additional amount of pressure was put on the valve; and consequently when the valve was set to blow off at 100 lb. pressure, an ordinary spring-balance valve might easily allow the pressure in the boiler to rise considerably above the pressure at which the valve was set. The "Paragon" safety valve that he referred to, which was illustrated in Plate 26, was provided with a double-pointed pin to keep it in position; a compensating lever of bell-crank shape was placed at the top of the pin, and the spring frame stood on the top of the compensating lever, the frame being kept down by the tension of the spring. When it was wanted to set the valve to any pressure, the adjusting nut was screwed up, and consequently the indicating pin at the top rose to the pressure desired; the drawing showed the valve set to 100 lb. pressure. The moment the valve began to rise and blow off, the short arm of the compensating lever would remain practically of the same length, whereas the virtual length of the longer or acting arm of the lever was reduced exactly in proportion to the rise of the valve. Instead of the leverage remaining the same as at first, $2\frac{7}{8}$ to $2\frac{1}{2}$, it would be reduced to $2\frac{1}{8}$ to $2\frac{1}{2}$ when the valve rose to its highest lift; and thus, although the tension of the spring was increased by the rising of the valve, the acting leverage became reduced in equal proportion, and the valve was allowed to blow off freely. An experiment had been made by Mr. Naylor with two 5 in. ordinary spring-balance valves set to blow off at 100 lb., and when they were in full play the pressure rose from 100 lb. to 145 lb.; the same experiment was carried out with only one Naylor safety valve of 2 in. diameter, and the pressure under the same circumstances rose to 105 lb. only. The two 5 in. spring-balance valves had a circumference of 15·7 in. each, giving a total circumference of 31 in.: they did not lift more

than about 1-32nd in., therefore there was only one sq. in. area of opening for the exit of steam. The 2 in. Naylor valve, having a circumference of 6·3 in., rose on account of the compensating arrangement about $\frac{1}{2}$ in., giving an exit of three sq. in. as compared with only one sq. in. exit afforded by the two 5 in. spring-balance valves. Although this might not represent the comparison with absolute correctness, it was sufficient to prove clearly why one construction of valve was superior to the other. The valve which he had described was quite inaccessible to the firemen or engine drivers, and there was no means of inserting a wedge in any place so as to increase the pressure. A testing lever was provided for the purpose of testing the valve, to see that it did not stick; that was a point which had not been provided for in Naylor's safety valve, but which he himself had found to be necessary. A valve of that description had been applied to a locomotive, and the men used to put their hands on the testing lever, and thereby put on extra pressure; but he had got over the difficulty simply by making the pin of the fulcrum, upon which the compensating lever was fixed, a screw, and the head of the testing lever a nut, so that the moment it was attempted to put a pressure on, the result was simply that the lever became unscrewed, instead of putting increased pressure on the valve. He might state that the Indian Government had "Paragon" valves fitted to all their Field boilers, which worked at 180 lb. pressure; and Messrs. Merryweather and Sons had used several hundred of these valves for their steam fire-engine boilers; the reason being that, the Field boilers making steam so very fast, it was found necessary to use a safety valve that could discharge the surplus pressure equally fast.

Mr. H. CHAPMAN observed that in the marine safety valve shown in Fig. 9 the springs were said not to be subject to the action of the escaping steam. But if the spindle bearing upon the valve was made so tight a fit in the hole through which it passed that the steam could not escape there, he should be glad to know whether an inconvenience had not been found from corrosion, not merely in setting the valve fast, but also in putting on more pressure than was intended.

Mr. E. A. Cowper did not quite agree that either of the so-called ordinary safety valves shown in Figs. 1 and 2 was of the commonest or best ordinary kind. One of them was shown with a flat seat, which was pretty generally given up now, and was very objectionable, owing to its tendency to keep down when blowing hard. A number of wings were objectionable for several reasons: they caused more friction, were more likely to jam from expansion when dirty from priming, and were much more liable to stick (owing to the guide being so short and large in diameter) than with a central pin as a guide to the valve, as such a guide was long and small in diameter, as usually made and indeed as he had made them himself for many years.

With regard to the experiments made with the Klotz valve, the statement given in the paper appeared to be that of Prof. Klotz. Of the two safety valves tried, the Klotz safety valve was $3\frac{1}{4}$ in. diameter, and the common safety valve $2\frac{7}{8}$ in., the Klotz valve being thus 1-5th larger in area than the other; but on looking at the pressure to which the steam rose while blowing off, it appeared that, when the valves were both loaded to 70 lb., by firing hard the Klotz safety valve was made to give a pressure of 76 lb., and with the other the pressure rose to $76\frac{1}{2}$ lb.; so that, as far as these figures went, the smaller common valve did the best; and he should like to know the rise of pressure that actually took place. If with the common safety valve the pressure ran up to 100 or 120 lb., it might be time to leave off the experiment; but there was no statement as to how much higher the pressure ran up with the common valve than with the Klotz in either experiment. He agreed with Mr. Webb that a valve of that sort ought not to be made too good a fit, for if the boiler primed the valve would be very likely to set fast.

Mr. W. Hartnell agreed in the opinion with regard to the new valve, that if the bell was made nearly to fit the internal cylindrical guiding portion it would probably be in danger of sticking; but if it was not made a near fit, then there appeared to him to be another objection, that the steam would rapidly escape between the two cylindrical portions of the valve, and the pressure where the steam

was escaping being less than it was inside the boiler, the value of the internal pipe would be almost lost. If a pressure gauge had been attached to the internal pipe, and the pressure noted at the moment when the valve began to blow off, and then the amount of variation noted, and the same thing done with the clearance made greater and greater between the valve and the seating, the effect of the amount of clearance would have been practically ascertained.

With regard to the pressure to which the ordinary construction of safety valve of good proportions and workmanship would allow the steam to rise in blowing off, he had tried many experiments on small boilers and a few on Lancashire boilers at about 60 lb. pressure, and had found the excess of pressure seldom exceeded 6 lb. He had also tried a Lancashire boiler 7 ft. diameter by about 28 ft. length with three pendant dead-weight hemispherical safety valves of $1\frac{1}{8}$ in. diameter and one of $2\frac{1}{2}$ in. diameter, and with hard firing the steam did not rise more than 6 or 7 lb. above the pressure to which the valves were set: that trial was made at the instance of a boiler inspector. He should be glad if Mr. Webb would give some information with reference to the rise of pressure in locomotives in blowing off, whether the steam was found to rise more than in the trial he had mentioned.

Mr. F. W. Webb replied that with the Ramsbottom system of two valves 3 in. diameter he had never found the steam rise in locomotive boilers more than 5 or 6 lb. above the pressure at which the valve was set to blow off. He had made a trial recently to ascertain what area of outlet would be sufficient to relieve a locomotive boiler hard fired: with a 1 in. pipe perfectly open he had managed to raise the steam to something like 10 lb. above the proper pressure; but on taking out the 1 in. pipe and putting in a $1\frac{1}{4}$ in. pipe he could not raise the steam pressure at all.

Mr. A. Paget observed that in this question of the safety valve it was a matter of great satisfaction to hear the very clear evidence given by members of such great experience, that with the ordinary safety valve, if suitably proportioned to the boiler and properly

made, the steam pressure in blowing off would not rise to the great extent that had often been supposed. He wished this fact had been more generally made known before, as a great deal of misplaced ingenuity and invention had been exercised in trying to obviate a difficulty which was now proved to be almost imaginary; for he believed that the ordinary safety valve when properly constructed would not stick fast, and would not allow any rise of pressure that could cause any danger to a properly constructed boiler. If that fact had been as well established amongst mechanical engineers, and as thoroughly believed in as it was by himself after what he had now heard, he thought a great deal of misplaced ingenuity and invention might have been saved. He was glad that it would appear clearly in the records of this Institution that men of experience, like those who had now spoken, had established the fact beyond a doubt, that the ordinary safety valve which had been so much abused was not an unreliable instrument as some inventors appeared to wish it to be considered.

Mr. W. Richardson mentioned an incident that had come under his notice in using a safety valve something like that shown in Fig. 1, only that the valve was made a segment of a sphere, without any guides below the sphere. Such a valve was applicable to stationary boilers, where levers and weights could be used; but of course it would not do for locomotive or marine boilers, on account of the shaking motion. It was admitted that there was a condition of still water in steam boilers, in which the water would carry more caloric than was due to the pressure; and when it got disturbed there was a very quick ebullition and development of steam by this excess of caloric. In the case to which he was referring it happened that the lever of one of the safety valves, with a weight at the end to produce 80 lb. pressure per sq. in., was swung clear over, liberating the valve; fortunately the guard to the lever was only an open fork, and when the engine was started the lever and weight were swung over clear away, and the valve blew out, giving a free discharge for the boiler. If therefore that force were generated from the still water containing more caloric than was due to the pressure, he considered the boiler

could not have relieved itself, had not the valve blown out as it did; and there must otherwise have been some great accumulation of pressure, perhaps so much that the boiler would have required to be very strong to carry it. This which had happened in his own experience, and which might happen in other places, was one of those things which ought to be provided for. It was known that a great number of boilers had exploded just when the engines had been started after a long stoppage; there were many such cases in the history of the boiler associations, and he attributed the occurrence to the stillness of the water enabling it to carry more caloric than was due to the pressure; then the moment the engine was started and the pressure relieved, the sudden ebullition and exit of steam increased the pressure as described.

Mr. G. D. Hughes enquired whether the Klotz valve had ever been applied with the object of preventing accidents to boilers from deficiency of water. From statistics given by the Association for the Prevention of Steam Boiler Explosions and by boiler insurance companies, he found that a great proportion of the accidents to steam boilers arose from deficiency of water from some cause or other; and from his own experience he believed that in the case of every stationary boiler, if it was to have a safety valve deserving that name, it should also provide against that frequent source of accident. There were instances in the Institution Proceedings of safety valves which had provided both for excess of pressure and also for deficiency of water.

The objections that had been urged with regard to the liability to stick between the seating and the outside of the valve now described were in his opinion very cogent; and he should be glad to hear whether the author had any suggestion to make on that point; some short time ago an accident had occurred in Nottingham in consequence of a safety valve sticking, whereby a life had been lost. It was an ordinary three-winged valve, the seating being made of cast iron bushed with brass, into which the three-winged valve was fitted. There were two of these valves upon the boiler, which was 20 ft. long and 6 ft. diameter. During the dinner hour there was a heavy fire

on, and all at once one of the valves rose so high in the seating and stuck fast there that steam and water escaped and scalded the attendant to death. On examining the valves he found that they fitted very tightly into the seating, more tightly he thought than they could have fitted when originally made. It then occurred to him to try the experiment that had been tried by their Past-President, Mr. Bramwell, in the case of the "Thunderer." The boiler was standing cold, and he got some water at a temperature of 212° and placed the valve in it; and upon then putting the valve into the seating it stuck quite fast in all positions; but when the valve was cooled down to about the same temperature as the boiler, it just managed to work freely. This showed the danger of making these surfaces fit so tightly that the slightest amount of priming would cause them to stick. Great care should be taken to give them sufficient liberty, seeing that the mere difference of expansion in the metals might cause the wings of the valve to stick fast.

Mr. T. ADAMS observed, with regard to the relative expansion of brass and cast iron, that a number of experiments had been made on this subject by the Board of Trade, and it had been found that the expansion of brass was not so much as double that of cast iron. The expansion of brass varied a little with its composition; the composition which he always used was 1 lb. of copper to $2\frac{1}{4}$ oz. of tin and $\frac{1}{2}$ oz. of spelter. The experiments were made with the metal at a temperature of 66° Fahr., at 212°, at a temperature represented by 50 lb. absolute steam pressure, and at a temperature represented by 100 lb. steam pressure; and from the results obtained could be deduced rules which would suit any temperature. At 212° the expansion of brass above cast iron was as 1·46 to 1, and at 100 lb. pressure it was as 1·60 to 1. The expansion of the seating was not simply as its diameter, but was nearly in the ratio of the difference between the inner and outer diameter; and in consequence of this relation he had made a 3 inch seating expand as much as a 6 inch seating by simply making the thickness of the metal greater in the 3 inch than in the 6 inch seating.

The ordinary safety valve he did not consider could be regarded as free from danger; there was sufficient proof that with the ordinary safety valve set to 60 lb. pressure, and with hard firing, the steam would rise to 120 lb.; and there was danger in that surely. Having just finished a calculation of the arrangement of the valve gear of the "Sidonia's" boiler (which burst a little while ago), he found that the action of the lever vanished at $1\frac{1}{2}$ in. rise of the valve, that is that the fulcrum of the lever and the joint of the stud bearing on the valve would then be in the same vertical line, so that the valve could not be made to lift higher with any amount of force. For the guiding of the ordinary safety valve he did not consider that a central pin was better than feathers. A given amount of clearance was necessary in each case; supposing, for example, the clearance was 1-32nd inch in the pin; then when the valve rose up from its seat, if it shifted from its central position the spindle would come against the guide at the bottom and against the pin of the lever at the top, and it acted with a leverage at that point, throwing the valve considerably further out of the central line. With feathers that was not the case, because the feathers guided close against the seating; therefore whatever was the clearance with the feathers, the valve could not go farther from the central line than that. In the paper now read it had been proposed to indicate the correct principles upon which safety valves should be constructed; but he did not consider that any of the safety valves shown in the diagrams were constructed upon the correct principle, which he believed to be that the force, the resistance, and the motion should all lie in the same straight line. With any system of levers the valve moved always in a straight line, while the levers moved in a curved line; consequently there was no correct principle in that mode of construction. The double conical spring shown in connection with the Klotz safety valve appeared to him a very objectionable form: the strength of a helical spring was as the diameter of its coils, and in the double conical spring here shown the central coils were double the diameter of those at the extremities; the proper method of constructing a helical spring was parallel, so as to be of equal strength throughout. It had been stated that the Klotz valve had

been applied on board ship; but he was not aware of its having been passed by the Board of Trade, and he thought the internal pipe would prevent it from being passed, as also would the internal cup. The most beautiful point about Ramsbottom's valve had not been mentioned either in the paper or in the discussion, namely that, instead of the hole for the spring attachment being precisely in line with the points of the studs bearing upon the valves, it should be made slightly below that line, for enabling the lever to act properly; then if the action of the valves were not exactly true, and one valve happened to rise before the other, the spring attachment would be brought nearer to the valve which rose and further from the one which did not rise, thereby increasing the pressure upon the former and at the same time relieving the latter. In a large number of the valves which he had constructed on that principle, he had made the hole for the spring attachment 11-16ths inch below the level of the bearing points of the studs upon the valves. Naylor's valve, which was said to be the best arrangement for the liberation of steam from the boiler, had been surpassed at the present day, but was a very good one at the time of its introduction; the worst feature of it was, he thought, that the steam in escaping destroyed the spring by gradually cutting it away. As to dead-weight safety valves, the best construction of dead-weight safety valve that had passed through his hands had been found to allow 17 lb. increase of pressure in blowing off, when set to blow off at 60 lb. in accordance with the Board of Trade rule for that size of valve. That was the best type of ordinary valve that he had met with; but there were many ordinary safety valves that allowed much greater increase of pressure in blowing off.

In the construction of helical springs, whether for safety valves or for other purposes, the proportions that he had found most advantageous in all cases were $11\frac{5}{8}$ to 3 for the ratio of the length or height of the spring to its external diameter; the pitch of the coils 29 per cent. of the diameter of the coil; and the side of square steel or the diameter of round steel 1-6th of this diameter. The deflection of such a spring under 1-6th of its breaking load would amount to 1-3rd of its diameter, when made of square steel, and to about 1-8th less when made of round steel. These proportions held

good for any range that might be required in the construction of helical springs: so that, in the case of one spring half the size of another, the small spring would be exactly half the diameter of the large one, exactly half the length, and exactly half the pitch, and it would be one-fourth of the section of metal; and the load upon this half-size spring would be one-fourth of that upon the full-size one. The Board of Trade formula for the strength of helical springs for safety valves, deduced from a series of experiments with 400 springs, was $\sqrt[3]{\frac{L \times D}{C}} = d$, where D was the helical diameter of the spring in inches, L the load in lbs., which was not to exceed 1-6th of the breaking weight, d the side of square steel or diameter of round steel in inches, and C a constant, which was taken to be 8,000 for round steel and 11,000 for square steel; this formula held good both for compression and for extension of the spring. Square steel was superior to round steel whether for strength or elasticity; it was 12 per cent. more elastic than round steel, and about as much superior in strength; it was in every respect the superior spring of the two.

Mr. E. B. Marten agreed with the previous remark that too large a safety valve was not good; and a larger valve than was necessary was a source of danger. He had some experience with large safety valves, and had seen safety valves of 2 ft. diameter: in that case however the weights were so large that when the valves did blow they caused jerks in rising and falling, and created more danger than that they were intended to provide against. He had more experience with the ordinary safety valves than with any other, and agreed that there was more safety in them than was generally supposed; otherwise there would have been many more explosions than had occurred. It was almost astonishing how well the ordinary safety valves did relieve the pressure, provided they were kept in anything like decent order. But they were frequently, even habitually, overloaded; when they were blowing off at the full pressure, it took a little more load to shut them: that was the reason why they were so often overloaded; yet as a rule they were what they were described to be, tolerably good safety valves.

Mr. Wilson explained, with regard to the specimen exhibited of the locomotive safety valve, that the two portions of the brass casing enclosing the valve were fastened together by two screws round the rim, so as to prevent any separation of the two portions from each other. They had originally been constructed with one half screwed into the other; but the objection to that plan was that a man might partially unscrew them and so jam the upper one against the lever; they were therefore now made to fit one within the other without any screwing. There was thus no possibility of getting a wedge in to separate them; and though he had once thought of bringing a flange from the casing a little over the valve, which would entirely prevent the chance of anything being put in, it seemed now unnecessary to do so.

With regard to the surfaces of the valve and seating sticking fast with priming of the boiler, it must be borne in mind that the valve and the seating were both made of the same metal, so that they both expanded alike; and the one was made an easy fit over the other. These were conditions which he thought were the best possible for preventing sticking or jamming of any kind.

With regard to priming, boilers ought not to prime if they were properly constructed; but the Klotz valve would act equally well if water went up the pressure pipe instead of steam; it was not a necessity that there should be steam up the pipe, and if the pipe were carried down into the water of the boiler, the results would be equally good. Moreover the rubbing surfaces of the valve and seating were vertical surfaces, which were the best possible form for letting away any water that might get in or any dirt or scum that might get between the two surfaces. If they had been horizontal rubbing surfaces it would have been very different.

He agreed that it was undesirable to put large safety valves upon boilers; in his own experience with locomotive engines he found that $3\frac{1}{2}$ in. diameter was the largest size of valve required for the largest locomotive engine. Even that size he thought might be safely reduced; and the smaller the valve the more desirable it was. In this respect he thought the Klotz valve possessed a great advantage, the escape of steam from a valve of small size being so very free

that a smaller valve might be put on of this construction than of the ordinary make. Naylor's valve was an indirect way of arriving at that which was so simply arrived at in the Klotz valve; the bent lever in the Naylor valve required to be very accurately made and adjusted, as did also the spring; and that arrangement was used for the purpose of obtaining what was effected in the simplest manner by means of the pressure pipe in the construction of the Klotz valve: in comparing these two valves therefore he thought one might certainly be spoken of as cumbrous and expensive, while the other was simple and economical.

In reference to the experiments with the Klotz valve, the statements in the paper were those of Prof. Klotz himself. In the experiments at the Avonside Engine Works the result was simply that with the Klotz valve the pressure could not be made to rise in the boiler more than 6 lb. above that at which the valve was set to blow off. In regard to the pressure with the ordinary valve rising to a dangerous extent, the boiler was being tested to 140 lb., and the pressure was running up so rapidly that it was thought wise to stop, as everything was getting very hot, and there might not have been sufficient control over the pressure. The Klotz valve had not been applied in connection with low-water regulating apparatus; it had been used hitherto simply as a steam-pressure safety valve for stationary and locomotive boilers, and for the application made by Messrs. Wood to the receivers of compound engines.

With regard to the centre pin being better than feathers for a safety valve, he thought they were both very bad, and that a construction like the Klotz valve was greatly preferable to either of them; it was a good mechanical construction, having the bearing point of the load at a low level, and a wide base to keep the valve steady and to guide it properly. With a centre pin, only the smallest possible space could be allowed for the rising of the valve. With reference to the enquiry about the corrosion of the central spindle bearing upon the valve, where it passed through a hole in a guide plate above, he had never found any objection on that score; it had never yet been brought under his notice in practice.

As to the construction of the spring for the safety valves exhibited, the proper mechanical construction in the case of a helical spring would undoubtedly be a cylindrical outline, like that employed for the Ramsbottom valves; but it was found more convenient in the present case to shape the spring in the double conical form shown in the drawings. The proper way of constructing it would certainly be to taper the material, so as to have a smaller diameter of steel at the small ends of the spring. That was a point in the manufacture, and the diameter of steel could be so tapered from the centre to the ends that each coil of the spring would take its proper share of the load. At present it would be expensive to get springs so manufactured, but there were means of doing it economically in that way; practically it was found that the double conical form of spring served every purpose, though a greater proportion of the load was certainly taken by the centre coils.

The PRESIDENT was sure the meeting would be very glad to accord a vote of thanks to Mr. Wilson for having brought this important subject before them in his paper, which had been the means of eliciting such an exceedingly useful discussion.

The vote of thanks was passed.

The following paper was then read:—

ON AN IMPROVED FORM OF SLIDE VALVE FOR STEAM AND HYDRAULIC ENGINES.

By Mr. FRANCIS W. WEBB, of Crewe.

For many years past attention has been directed to finding some means whereby the great wear and tear of the Slide Valves and port faces of engines might be lessened. This object the writer thinks he has succeeded in effecting to a great extent by the valve to be described, which has been worked successfully for 1½ years. It was first brought out by the writer in 1869, but not being at that time connected with locomotive engineering he had not then the opportunity of trying it. The valve differs from the slide valves in ordinary use in being made circular and free to revolve in its buckle; so that if the valve should have a tendency to seize in any one part of the sliding surface, which would put more friction on that particular side, it will immediately begin to revolve, and so rectify itself by bringing different portions of the surfaces to bear. By this means the grooving action is avoided that arises in ordinary rectangular slide valves from their unequal bearing, the sides of the rectangular valve having a continuous bearing that is never out of contact, whilst the ends of the valve travel across the open ports. The valve wears out of level in consequence, and leakage begins almost from the time of starting, and increases until it becomes so bad as to necessitate refacing the valve and the port face, often a troublesome and expensive process. This has been found a serious practical objection in ordinary slide valves, and different means have been tried for reducing it, such as plugging the valve face with white metal, or drilling open holes in the slide flange; but these only partially meet the case.

In this Circular Slide Valve, by its rotation in the buckle, all parts of the face are made to bear alike, and any grooving action is

effectually prevented by the circumstance that an inequality or increased friction at any one part causes the valve at once to shift its position by turning round in the buckle. The result is that no grooving action ever takes place, and the valve retains a perfectly level polished face.

This valve is shown in Figs. 1, 2, and 3, Plate 27, as applied to a locomotive engine with outside cylinders. The valve spindle A is carried in the usual way with a bush and gland at one end, and a bush at the other; it is supported however by the slipper B, as it has also to carry the weight of the valve, the usual ledge for taking the weight off the ordinary rectangular valve not being applicable in this case. The valve C is turned true in the lathe on the face, steam and exhaust port edges, and also where the buckle fits; and this is left sufficiently slack when cold to be quite free when the brass or iron valve is expanded by heat in the wrought-iron buckle. In Fig. 3, the outer curve of the port D is struck with the same radius as the valve over the lap, and the inner curve of the port with the same radius as the exhaust cavity of the valve; so that the ports open simultaneously all the way round the valve, both for lead and for exhaust. This of course can be varied by altering the curved shape of the port, if it is thought desirable to let the lead or exhaust open in the centre first, so as to make it more gradual. The clearances E and F at the top and bottom of the face are so arranged that, during the revolution of the valve in the buckle, every portion of the valve face will pass over them; this also relieves the pressure on the valve to a slight extent without affecting its efficiency, and affords a ready means of getting the valve face fully lubricated. One of the pair of valves shown on the table has now run about 20,090 miles, and the other 4,090 miles; and they have been merely taken out to show their condition, that it may be seen that the faces remain true, though they have not been faced up since first started. These valves are of cast iron, and their condition shows that with this form of valve cast iron can be used for high-pressure engines.

In connection with this particular form of valve, the writer has also arranged a method of taking off the pressure by means of a back

ring working against the steam-chest cover, but this has not yet been put to work; and with the very good surface that can be maintained with this valve, it does not appear to be required, as a very small leakage through the back packing-ring would soon overbalance any saving that may be effected. That method of relieving a rectangular valve was first tried many years ago by Mr. A. Allan, formerly the works manager at Crewe, in the engine "Phalaris" in 1844, and subsequently in the engine "Velocipede," which was built in 1847. Figs. 13 to 15, Plate 30, copied from the original drawing, show how the back packing-ring was applied; and in the opinion of the writer, if the valve-chest cover had been sufficiently strong to avoid warping under the pressure, it would have been quite successful.

In Figs. 4, 5, and 6, Plate 28, is shown the application of the circular slide-valve to an inside-cylinder locomotive.

Another application of the circular valve, which the writer has found extremely useful, shown in Fig. 7, Plate 29, is in the hydraulic capstan engines, where the slide valves have proved a continuous source of trouble through galling, as seen in the two samples shown on the table of the ordinary rectilinear valve out of an Armstrong capstan. But the sample exhibited of the circular valve shows how completely its revolving action rectifies itself; in fact, taking any number of valves from different engines, the surfaces are kept so true and perfect that when only simply wetted one will support the weight of another. It may be mentioned that the circular valves on the table had been working continuously night and day at Camden Station for eighteen months before they were taken out, under a pressure of 700 lb. per sq. in., while the rectangular valves have only worked seven and ten months respectively.

A further application of the same principle of valve is in one of Brotherhood's simple direct-acting three-cylinder capstans. This valve has been at work for some months at the North Western Railway works at Crewe, under a pressure of 350 lb. per sq. in. For this the writer has designed the arrangement shown in Figs. 8 to 12, Plate 29, which has so far proved successful. It consists of a brass disc G, Figs. 11 and 12, grooved concentric on its face to receive three cast-iron pieces I, in each of which a small circular brass valve

J, Fig. 10, is inserted; the cast-iron pieces are used in order to get sufficient rubbing surface in the groove of the brass disc to avoid cutting. The brass disc is rotated by an eccentric pin H, turned by the capstan crank-shaft, on the opposite side to the one on which the valves are placed. The port face has three radial recesses, in each of which are formed an inlet and outlet port, Fig. 9; the valves are of the same diameter as the width of the recesses into which they are placed, and they have a reciprocating motion imparted to them by the eccentric movement of the brass disc. The inlet ports are made in a similar manner to those of the locomotive previously described; but the outlet port, for a single-acting valve like this, is made circular for the sake of simplicity. A set of these valves has just been taken out, and is shown on the table, that their condition may be seen after being at work a considerable time.

Mr. Webb mentioned that there had been some trouble at first with the slide-valves of the three-cylinder hydraulic capstan which were first designed; these were rotary three-ported valves of phosphor bronze, working on seatings of the same metal; but the seatings had since been made with a wood face, and now gave no trouble when working under a pressure of 700 lb. per sq. in. The small slide-valves of the three-ram hydraulic capstans had previously given a great deal of trouble, and he had tried the circular slide-valve in the first instance in an Armstrong capstan; he had now got nearly every ram-capstan on the London and North Western Railway working with these valves, and they were all in good condition. One of those exhibited had been working night and day for nearly two years, since Sept. 1875, and as could be seen was still in excellent condition. Of the two cast-iron locomotive valves exhibited, one had run 20,090 miles, and had worn down perfectly true, only 1-32nd

inch having been worn off. A brass valve of the same kind, working on the other side of the same engine, wore equally well as regarded keeping a true face, but the metal wore down as fast as the ordinary rectangular brass valves did, the wear amounting to 3-16ths inch in the brass valve after running 16,000 miles. In order to see whether there was any difference in the two port faces, the other cast-iron valve exhibited was then put in the place of the brass valve, and had now run 4,090 miles with scarcely any appreciable wear; and on placing these two valves together, face to face, it was seen that the faces of both had worn perfectly true, and that thus the difficulty of the wear and tear in the ordinary slide-valves had been got over, as well as some considerable portion of the friction.

Mr. J. C. WILSON considered there could be no doubt that this valve was a very good construction for preventing grooving, and for wearing equally well all over; for it was well known that even the fact of rounding the steam ports at the ends with an ordinary square valve had a decidedly beneficial effect. It appeared to him however that with this form of circular slide-valve there must be a greater amount of wire-drawing of the steam, on account of the curved form of the port, than with the square straight-ported slide-valve. Another objection that he noticed was the increased length of the steam ports; the capacity of the ports must be greater with a valve of this kind than with an ordinary slide-valve, the length of the port to the corners of the semi-circle being greater than if the port was taken square across; that would occasion a greater waste of steam at every stroke. Otherwise, in regard to the wear and tear of it, all experience went to prove that it would certainly be a very good valve.

Mr. BENJAMIN WALKER mentioned that in making some experiments about twenty years ago with regard to the use of steam at a pressure of 250 lb., he had found that the slide-valves could not be kept in good condition at all; whatever sort of metal was used, cast iron or brass, the friction was so severe that they were very soon destroyed. A cylindrical piston-valve was then introduced, the body of the valve being made like a common piston with two grooves turned in its

circumference, so as to leave one broad ring in the middle of the piston, and a smaller one beyond it at each end; the steam at the back of the valve pressed it against the port, and it was merely allowed to move freely round on its spindle, and this moving round overcame all the difficulty of friction and grooving, notwithstanding that the full pressure of the steam was on the valve. In the case of some large engines that he had made with these piston-valves the valves had recently been taken out after as much as sixteen years' work, not because they were any the worse for wear, but because the corrosion from the tallow had so destroyed the spindle and arms of the valve that it had become dangerous to work it longer; the face of the valve however was as good as at the beginning. The sliding motion and turning motion taking place at the same time, the valve was constantly kept moving, and there was no possibility of corrosion or grooving of its face. The hydraulic valve shown in the drawings as applied to Brotherhood's three-cylinder capstan was he thought successful: he could not imagine any happier idea than allowing the valve to turn round; it overcame the difficulty of grooving, and was well adapted to keep the circular valve perfectly true. If that plan were applied to a valve to be worked by hand, he thought there would be more total pressure upon it than upon the ordinary rectangular valve, and that some difficulty would arise to the man working it; when the seat was made of gunmetal, and the valve as small as possible, it would be much more easy for the man to handle it. For example, in moving the Bessemer converters backwards and forwards there would be an increased surface of the valve exposed to the pressure, causing greater friction, and it would give the man increased labour, and less facility for handling the cranes with exactness and ease. He was sure Mr. Webb had done mechanical engineers great service by this contrivance, and he had no doubt that it would be adopted extensively.

Mr. P. G. B. WESTMACOTT observed that there seemed to be very excellent results from this circular slide-valve; but although the ordinary rectangular slide-valve had in some cases given a great deal of trouble, there were instances in which it had worked well for a

great length of time. For instance, at the Birkenhead corn warehouses there were twenty-eight hydraulic engines, many of which had now been at work night and day for about nine years under a pressure of 800 lb. per sq. in., and out of the whole lot of slide-valves there were only two that had required to be replaced. There were also slide-valves that had been put in hydraulic engines at the Allenheads lead mines in Northumberland about twenty-seven years ago, which were still working and had never been replaced. It was difficult to account for the difference in the working of valves in one place and in another. The capstan engine had this disadvantage, that being generally an underground machine it received most of the dirt that gravitated to the bottom of the pipes. He should be glad to know what was the mixture of metal that had been used in the circular valves replacing the rectangular valves in the hydraulic capstan at Camden station. The valve that in his experience gave least trouble was the mitre valve. Some mitre valves had been working a long time, about ten years, under a pressure of 800 lb. per sq. in., and had never been touched. The valve that they were chiefly using now at Elswick was the trunnion valve. It gave very good results; he attributed this a good deal to the fact that the distance through which the valve had to travel was small; the port was $\frac{3}{8}$ in. long, so that in every revolution of the engine the valve travelled through a distance of $\frac{3}{4}$ in. After three years' very hard work, night and day, some of these valves were only reduced 0·02 inch in diameter. One advantage of the trunnion valve was its great simplicity; it had no levers and no pins, and the travel was small.

Mr. WEBB replied, respecting the metal used for the circular valves of hydraulic capstans that had been referred to, that it was a specially hard mixture composed of 4 parts tin and 16 parts copper.

The PRESIDENT enquired whether Mr. Westmacott had any experience in the use of phosphor bronze for the valves.

Mr. P. G. B. WESTMACOTT replied that he had tried it, but found it did not wear so well as a hard mixture of gunmetal.

Mr. J. Platt said he had had some experience of a circular slide-valve under hydraulic pressure, shown in Figs. 16 and 17, Plate 30, but the result had not been at all satisfactory. Thinking that the stroke alone was not sufficient to cause the valve to revolve, he had given it a positive turning motion, rotating it by a ratchet wheel on the back of the valve rotated by pauls fixed in the valve-chest, so that the reciprocating movement of the valve gave it also a rotating movement. That plan kept the face perfectly smooth, but he could not get the valve to keep tight. Whether there was something in the twisting motion that relieved the pressure on the face, he could not determine; certainly it had not been at all satisfactory. It was a brass valve $2\frac{1}{8}$ in. diameter with a 1 in. hole through the centre, and was partly balanced, the pressure being excluded from the back by means of a relieving ring of the full diameter of the valve face, with a leather packing ring arranged to give one-third the area for pressure on the face. He had tried plugging the centre hole, to make it like an ordinary slide-valve, but it was still not tight; then the rotating motion was taken off, and it was found to be tight. Without the relieving ring the valve was tight, but with 1500 lb. pressure it soon began to cut, and it cut more on one side than on the other, and although free to rotate it did not rotate; it scratched the face in a manner that showed there was no rotation, although the conditions were favourable for its rotating. He did not understand how the circular slide-valves described in the paper got a rotating motion, as he could not see how an ordinary slide-valve would rotate without a positive rotary motion being communicated to it.

Mr. E. A. Cowper thought that with the brass valve of the dimensions just given there had probably not been sufficient area of bearing surface under the high pressure employed, and that the metal had seized naturally; the pressure of 1500 lb. per sq. in. was so high that no brass would stand it without seizing. On the other hand, if the pressure was taken entirely off the valve by the relieving ring at the back, it appeared to him that there would be no pressure on the valve to keep it up to the face, and the lever actuating the valve took its bearing against the valve rather high up from the face,

so that there was a tendency in the valve to tip, which would account for its not keeping tight when balanced.

Mr. F. C. Kelson observed that with the circular slide-valve described in the paper it appeared to him the exhaust port would not open to the same extent as the steam port, but less; and he should be glad to know whether that was found to affect the working of the engine.

Mr. Webb said that, with regard to wire-drawing, there was no more wire-drawing with the circular slide-valve than with the ordinary rectangular valve: the outer curve of the port being struck with the same radius as the valve over the lap, the port opened simultaneously all round from end to end; and the same was the case in opening for the exhaust, the inner curve of the port being struck with the same radius as the exhaust cavity of the valve; the rate of opening of the circular slide-valve was precisely the same as with an ordinary valve having the same lead and travel. With regard to the comparative contents of the port, it would be seen from the drawings that the port was not any longer with the circular valve, but really slightly shortened. As to the revolving of the circular slide-valve, the moment that there was a little more friction on one side than on the other, the valve started and began to revolve.

The President moved a vote of thanks to Mr. Webb for his paper, which was passed.

The following paper was then read:—

ON THE MECHANICAL APPLIANCES USED IN THE CONSTRUCTION OF THE HEADING UNDER THE SEVERN, FOR THE SEVERN TUNNEL RAILWAY.

BY MR. JOHN J. GEACH, OF NEW PASSAGE, NEAR BRISTOL.

The object of this paper is to record the results attained in actual every-day work by the machinery used at the Severn Tunnel, without entering into any comparison of different classes of rock drills. Simplicity in all cases has been aimed at, so that ordinary labourers could work the machines with very little practice.

The subject has been arranged under the following heads:—

Soundings by machine.
Sinking of the first Shaft.
Driving the Heading by hand, by the McKean machine, and by the writer's machine.
Details of the Rock-Drilling Machine in use.
Details of Rock-Drill Carriage.
Details of Air-Compressor, and method of cooling.
Details of Pumping Machinery.

Soundings.—These were taken by the aid of the machine shown on the table. It consists of a light drum, round which the brass sounding wire was coiled; a worm on the same shaft gearing into a wormwheel, and an adjustable index-hand and plate. The lead used was 12 lb. weight. This machine enabled two soundings per minute to be taken in 60 ft. of water. The plan followed was to sound on parallel lines north and south of the parliamentary centre line, at intervals of 30 ft. apart. After about twenty of these lines had been sounded and plotted, a final line was decided on as the centre line of the tunnel; and along this soundings were again taken more numerous

than before, and so well did these soundings agree that two would often plot on the same spot, although taken at different times. The machine shown was designed and made for the purpose, and was used in a row boat about 20 ft. long and 6½ ft. beam. Owing to the current, the soundings were only taken about half an hour before and after high and low water. A general section of the river Severn along the line of the tunnel is shown in Fig. 1, Plate 31; and the enlarged section in Fig. 2 shows the shaft, and the distance to which the heading has now been driven.

Sinking of the first Shaft.—As soon as the final centre line for the tunnel was fixed, the position of the shaft was marked out, and sinking was commenced by hand through sand, sandstone, and marl, down to 45 ft. deep, at which depth the hand-pump, skips, &c., failed to keep the water under. As a temporary measure one of Tangye's "special" pumps was put to work in the shaft, and by its aid the sinking was carried 25 ft. further, when it got overpowered. A bucket-lift on the Cornish plan was then erected, which kept the water under at 4 strokes per min. As the shaft went down, a plunger-lift was coupled on the same engine, working in a tank, into which the same bucket-lift raised the water. With the aid of these lifts the shaft was sunk to the required depth of 200 ft., having passed through top soil, sand, sandstone, marl, conglomerate, pennant, clay shales, coal shales, millstone grit, limestone boulders and clay, and into ironstone. When down to the proper depth, another similar plunger-pump was erected at the bottom of the shaft, and the one with which the shaft had been sunk was also fixed at the bottom: so that there were two plunger-lifts fixed for draining the heading. Two suitable cages were now erected in the shaft, with wood guides, and were provided with catching gear. These cages were suspended by $\frac{7}{8}$ in. round steel wire-ropes, both ropes working on the same drum, but wound on in opposite directions. The drum was 6 ft. diam., and was geared 1 to 4 to a pair of horizontal engines with 10 in. by 14 in. cylinders, fitted with reversing gear and with two brakes, one on the drum direct and the other on the crank-shaft of the engine.

Driving the Heading.—As soon as the above work was finished, the driving of the heading was started by hand labour, and the progress that could be made was not more than 1 ft. per 24 hours. The McKean rock drills were then put at work, and for the next month the progress averaged 2 ft. per 24 hours. These machines worked from January 1875 until the November following, when they were entirely worn out; the average rate attained was 6 ft. per 24 hours. In November 1875 the author's improved rock-drilling machines were put at work, and in driving by their aid till the end of January 1876 the average speed in the same pennant rock had risen to 8 ft. per 24 hours. This has since been much exceeded: 20 yards in 6 days, or at the rate of 10 ft. per day, has been driven in solid rock; and when the ground was more favourable as much as 26 yards in the same time, or at the rate of 13 ft. per day. Not only has this been done, but the average speed in the same rock is now rather more than 9 ft. per 24 hours.

Rock-Drilling Machine.—This rock drill differs from most rock-drilling machines in being made strong and heavy, and having a very efficient system of rotation and method of holding the drill. The latter feature is quite new, as far as the writer is aware; its extreme simplicity, and the entire absence of any loose parts, must commend it to practical men, whilst its holding power is ample. It is also self-centering, which is very necessary with such men as work these drills, being merely ordinary labourers. This method of holding the drill has never been found to give any trouble, and the tool is also easily extracted.

The following is an example of the time occupied in boring by this machine for blasting, the work being done 4432 ft., or more than $\frac{3}{4}$ mile, from the bottom of the shaft, which is 200 ft. deep; a sample of the rock is exhibited on the table, showing some parts of the holes bored. The rock-drill carriage was moved forward from a siding at 11·30 a.m., and taken to the face, coupled up, and fixed; at 11·41 a.m. the machines commenced boring, and in 1 hour 6 min. twenty holes were finished, averaging 2 ft. deep each; the rock-drill carriage was then uncoupled and run back to the siding, and the

holes were charged with dynamite ready for firing at 1 p.m.; total time occupied in boring and charging, 1 hour 19 min. This is an ordinary speed, no means having been taken to obtain extra quick work. Two of the rock-drilling machines were used, one on each side of the carriage; and the left-hand machine was worked by a man whose experience of machine drilling only extended over twelve days. The following are the particulars of a few of the holes in the order in which they were bored on this occasion by this machine and man :—

No. of hole.	Boring commenced.	Time occupied in changing drill.	Boring finished.	Total Time. *	Depth Bored.	
					Total.	Per min. *
No.	H. M.	Sec.	H. M.	Min.	Inch.	Inch.
1	11 41	20	11 44	3	18	6·0
2	11 46	20	11 51	5	26	5·2
3	11 52	50	11 59	7	28	4·0
4	12 1	15	12 5	4	24	6·0
5	12 6	55	12 10½	4½	31	6·9
6	12 15	35	12 19½	4½	24	5·3

* Including the time occupied in changing the drill.

These six and the remaining four of the ten holes were all bored by two drills ; it is found as a rule that four drills put down 40 ft. depth of hole, or each drill bores 10 ft. before wanting sharpening, which is done in the forge, no fitting or grinding being required. These holes are all bored truly cylindrical, proving the perfect rotating and boring power of these rock drills. Other machines that have been used by the writer have been found defective in this particular, leading to the drill being often jammed in the hole.

The Rock-Drilling Machine is shown in Figs. 3 to 8, Plates 32, 33; it consists of a cylinder, with piston and rod and valve-gear, mounted on a slide-bed. The cylinder A has no loose covers or split glands, which in some machines have proved a source of great trouble

and expense. The piston and piston-rod B are made in one piece of steel. The piston has two rings of steel, and the rear end of the rod, $1\frac{1}{2}$ in. diam., is cut with spiral grooves making one complete turn in 32 in.; this fits into a long cylindrical nut C, on the centre of which is formed solid a ratchet-wheel $3\frac{1}{4}$ in. diam., having 28 teeth. Into these teeth a paul engages, Fig. 5, to prevent the rotation of the drill and piston-rod in more than one direction. When the piston-rod is making its full stroke, the paul slips over three teeth per stroke and holds them; the rotation of the drill and piston-rod is effected in the backward stroke, and the forward blow takes a straight direction.

The front end of the piston-rod is $2\frac{1}{4}$ in. diam., and holds the drill D, Fig. 3, in a conical socket, which is $1\frac{1}{2}$ in. diam. in front, and coned to $1\frac{1}{8}$ in. at 4 in. back. A keyway $1\frac{1}{4}$ in. by $\frac{1}{4}$ in. is cut through the rod, for the purpose of forcing out the drill when another is required. Over the end of the piston-rod in which the coned hole is bored, a steel hoop $\frac{3}{4}$ in. thick is shrunk, to prevent the coned end of the drill from bursting the end of the piston-rod, and to give a certain amount of elastic clip. It is found that with this cone a drill never slips or sticks so fast that it cannot be readily driven out. No special precautions are necessary, except that as the coned end of the drill is entered into the end of the piston-rod it is passed through the hand and so cleaned. No driving in of the drill is required; the drill is entered, held loosely by the hand in place, and the first stroke of the machine fastens it; no further precautions are necessary. The drill is securely and truly held, and has never been known to fail in any degree during months of continual work. The end of the drill is turned to the same cone as the socket in the piston-rod, but no grinding in or special fit is required.

The valve gear consists of two pistons on one rod E, Fig. 3, sliding in a cylinder; the air is taken in between these pistons, and by their motion is alternately admitted to and let out of the ends of the drill cylinder A. The ports are small, 1 in. long, $\frac{3}{8}$ in. wide, and $\frac{1}{2}$ in. deep, and are placed $\frac{1}{2}$ in. short of the cylinder ends to form a cushion. This protection is more than enough, and the piston never strikes the ends of the cylinder, even if run full speed without any drill in the

rod. The valve-pistons have for packing C rings with a spiral spring behind, one in each piston; the solid part of the piston is toward the port, Fig. 6, so that there is no risk of the ring getting into the port. The valve is driven by a ball tappet F on the piston-rod, through a quadrant mounted on a pin, as shown in the plan, Fig. 3.

The method of feeding the drill forward as it bores the hole is by a $1\frac{1}{2}$ in. feed-screw G rotated by hand. The writer has tried automatic feed, and is convinced that, in such a variable material as is the rock met with in heading-driving and shaft-sinking, hand feed is the simplest. On paper, automatic gear looks best; but when machines come to work, as they have to do, under varying conditions and hard usage, simplicity is of the greatest importance. It is found also in the work that if the man working the machine is encouraged he will soon learn to feed the drill forward exactly as the hole is bored. Comparisons of hand with automatic gear are often based on the work of a self-acting lathe or other shaping machine; but this is not, in the writer's opinion, a fair comparison. In the one case the tool is acting on a material which is known and has been seen; and in the other the working is in the dark to a great extent, owing to the presence in the rock of joints and backs and layers of soft material. The writer tried the automatic gear of the McKean drill in ironstone with thin joints of clay shale, and found it would not bore through this rock and shale at an oblique angle with the joints; and yet the same machines, by using the hand-feed gear, bored through both the ironstone and the clay-shale joints.

The machine bed H is held to the clamp on the crossbar J of the rock-drill carriage by clip-bolts and set-screws, Figs. 6 to 8, Plate 33; and the crossbar is again clamped to the vertical face of the rock-drill carriage, as shown in Figs. 10 and 11, Plate 34. The drills in use vary from 2 ft. 6 in. to 6 ft. 6 in. long, worked in sets, so that the right and the left-hand machine would have to a certain extent drills of equal lengths. Long and short drills work well, and in ordinary use will without sharpening drill through 10 ft. of rock each. At the end of this depth of work the drill is still sharp enough to bore 20 ft. further, but in this rock it is reduced in diameter nearly $\frac{3}{8}$ in., so that it is necessary to have the drill again jumped up, that the borehole

may be large enough for the dynamite cartridges to pass freely to the bottom of it. The drills used are all of a cross section on the point, Fig. 9, Plate 33; and the cutting or abrading edge is sharpened in the forge and roughly filed up when hot, so that the leading angle is about 75°. Two of these drills are exhibited to the meeting; one requires jumping up and sharpening, and the other is dressed ready for boring; these clearly show the action of the rock on the tool. The whole of the castings for these machines are of phosphor bronze, the bed of wrought iron, and the remaining parts of steel.

Rock-Drill Carriage.—The carriage for the machine is shown in Figs. 10 and 11, Plate 34, and was designed specially for this work; it has done good service and is now equal to new, the only wearing parts being the corner supporting screws L, the roof screw K, and the bearing wheels. This carriage runs on the same gauge of 21 in. as the trolleys, and when not in use is run back into the first passing place or turn-out. It is all in cast iron except the screws, nuts, and axles, and was made at Swindon from the writer's drawings. The base plate M of the carriage is 4 ft. 6 in. long, 2 ft. 6 in. broad, and 1 in. thick, flanged all round. The wheels are small, to keep them under the base plate and the carriage low down; and are 6 in. diam., of chilled cast iron. They rest on two heavy steel rails N, 8 ft. long, held together by three cross stud-bolts and nuts, which are advanced as the heading progresses; and matching pieces of rail are inserted behind until there is length enough to put in an ordinary rail, when the same process is again repeated. The heavy framed steel rails N are always kept in front as a foundation for the carriage to rest on in working.

On the base plate is firmly bolted an A frame, with the front limb vertical; and through the head of it a strong screw K works, 2½ in. diameter, so as to jack the stand firmly on its bearing screws L, which are first run down on the rails to relieve the wheels and axles. The vertical face of the A frame is planed, and has a section of 2 in. by 6 in.; and on it is a clamp P, which holds the crossbar or tube J carrying the rock drill. This clamp clips the vertical face of the carriage and also the crossbar, and by slacking the back nuts the

clamp and crossbar can be raised or lowered; and the front nuts similarly hold the cross tube. Only two rock-drilling machines are worked on this bar at once, as shown in Fig. 11, although four could be worked with two clamps and bars; but the writer does not think any great increase of speed would result from four being used, as two machines now bore twenty holes in 1 hour and 6 or 7 min., and if four were used it would take nearly as long, owing to the cramped place of 6 ft. 6 in. square in which the men have to work.

On the rear leg of the A frame are air and water distributors, one on each side, to which are connected the air and water pipes by hose and couplings; and they are provided with outlet cocks, one for air to each machine, and one for water to each borehole. The air is brought forward by 2 in. wrought-iron pipes screwed together, and the water by 1½ in. and 1 in. pipes. The air pressure is 60 lb. per sq. in., and the water has a head now of 180 ft. A powerful jet of water, playing in the hole as it is bored, is found of the greatest service, especially in upward holes; the water is spurted into the boreholes through nozzles ¼ in. diameter.

Air-Compressors or Pumps.—At first the air was pumped into the receiver by a pair of inverted single-acting cylinders, 12 in. by 15 in.; a trunk closed with a valve on the upper end worked in each cylinder, the trunks being driven by connecting rods from two opposite cranks on one shaft, on which a pulley 5 ft. diam. and a flywheel were fixed. The pulley was counterbalanced, but it was soon found that the belt, although 8 in. broad and double, would not stand the work; consequently a vertical engine, with 9½ in. by 18 in. cylinder, was coupled on at right angles to the cranks of the air pump. This worked fairly well, but the delivery and also the inlet valve gave much trouble by breaking and sticking up.

Another air pump and engine were then considered requisite to avoid any delays, keeping the old one as a stand-by; and the present air pump was designed for the purpose by the writer, as shown in Figs. 12 to 19, Plates 35 and 36. It was made intentionally larger than the present requirements, and now supplies enough air when driven at a slow speed. The air and steam cylinders are each 13 in.

by 18 in., mounted vertical on two similar standards, and coupled to the crank-shaft at right angles to each other. The air cylinder is so made that, if anything goes wrong with the valves at either end of the cylinder, the defective cover and valves can be taken off, and the cylinder worked single-acting. There are two inlet openings for air, which is intended to be forced into the cylinder by a fan, so as always to charge it fully for each stroke; also two outlets coupled to a 4 in. pipe leading to the air receiver.

This receiver is 28 ft. long and 5 ft. diam., formerly an egg-ended boiler; it is usually kept nearly half full of water to cool the air during compression in the cylinder, as afterwards explained. The receiver is fitted with water gauge, pressure gauge, and safety valves; and a 2 in. pipe is coupled to it, leading down the shaft and to the face of the heading.

The inlet and outlet valves of the air pump are of brass, arranged four in each cover so as to give the least clearance, as shown in Figs. 14 to 16, Plate 36. They have been found to work well, not cutting or otherwise getting out of order; their weight is balanced by springs, as shown in Figs. 17 and 18.

The air cylinder is jacketed for water to keep it cool; but the jets of water that are injected keep the cylinder &c. cool enough without the use of the jacket. At each end of the cylinder a small ball-clack is screwed into the casting; and these clacks are coupled to the lower part of the air receiver by a copper pipe, $\frac{3}{8}$ in. bore. These small clacks are so arranged that when the pressure in the air receiver is greater than that in the cylinder a jet of water is injected, and thus the air is kept sufficiently cool. The air and water are carried on together to the air receiver, where the air parts with nearly all its water. The receiver is filled half way up every week, and this quantity of water does not lower more than 6 in. during the six days' work, the water being continually circulated, heated, and cooled, through the air cylinder and receiver. The piston of the air cylinder is hollow, and kept filled with water through small holes in the top, as shown in Fig. 19, Plate 36; and the water has access to the circumference of the piston, to keep the rubbing surfaces lubricated in working.

Pumping Machinery.—At first, as already stated, a Tangye "Special" pump was used; but this soon got overpowered and worn out, and the grit from the rock cut the pistons and cylinders so badly that it could not do the work required. Quick-running pumps of that or any other class are not suitable for sinking; and the writer thinks for this purpose nothing is better, when the quantity of water is not large, than a plain bucket-pump driven off a spur-wheel. The pump by which the shaft was sunk is 15 in. diam. with 7 ft. stroke, and is driven through a ⊥ bob with balance boxes, off the crank-pin of a 9 ft. spur-wheel, which is geared to a pinion on the crank-shaft of a horizontal engine in the proportion of 1 to 5. The cylinder of this engine is 18 in. by 26 in., worked with 60 to 80 lb. steam. All the parts are massive, on the locomotive type, and it is fitted with reversing gear. The ordinary speed of the pump is 10 to 12 strokes per min. The wood main-rods of the pumps are 11 in. square, and as the shaft went down the bucket-lift was worked off one side of the rod, and the plunger-lift, 15 in. diameter, off the other side. After the shaft was down, this plunger was fitted to the lower end of the main rod, thus doing away with the bucket-lift and all its wear and tear, and working direct. Another similar engine and pump were then put up as a duplicate, and to be ready to help if required. These engines were supplied with steam by two multitubular boilers, 20 ft. long and 5 ft. diam., assisted by a broad-gauge locomotive boiler.

A 40 in. Cornish beam-engine, 10 ft. stroke, was then added, with an 18 in. plunger-lift, 9 ft. stroke; this engine is very economical, and works steadily in a very satisfactory manner. As the water was still on the increase, from 80,000 to 100,000 gall. per hour, another plunger-lift, 15 in. diameter, and with the same stroke, was added to this engine. With this extra load a steam pressure of 45 lb. per sq. in. was required, cutting off at about ¼ stroke, and a vacuum of 26 to 28 in. was obtained. This engine has three Cornish boilers, 5 ft. 6 in. diam. and 24 ft. long, with eight Galloway cross tubes.

Near the old shaft a new one is now being sunk for permanent pumping purposes; and to do this quickly, a cross drift was driven from the present heading, and a 10 in. hole was bored down to it so as to

unwater the ground. This new shaft is now down 150 ft. out of 200 ft. total, and will be lined with cast-iron tubbing plates; the sump for the pumps was sunk out in the dry before the 10 in. bore-hole was down, and the girders for carrying the pump work were built in place. The engine is a direct-acting one, with 50 in. cylinder and 10 ft. stroke, and will be fitted with a surface condenser and steam jacket; and the pump is 26 in. diam. and 10 ft. stroke, and is worked through wrought-iron main-rods 5 in. diam. All the work in this pit is arranged for two such engines and pumps; and there will also be room for two more similar pumps, proposed to be driven by a beam engine with 72 in. cylinder and 10 ft. stroke. The valves in this and the other two pumps are Harvey's four-beat valves; they work with the least lift, and all shocks are avoided. The 50 in. engine has three boilers, 5 ft. 9 in. diam. and 28 ft. long, with 3 ft. 6 in. flues, each with ten Galloway cross tubes; the working pressure will be 50 lb. per sq. in.

Mr. GEACH exhibited the apparatus that had been employed in taking the soundings for determining the line of the tunnel; and also specimens of the drills used in the rock-drilling machine, showing their condition when new and after the usual amount of wear. He mentioned that in the intended visit of the members to the Severn Tunnel works after the meeting the rock-drilling machine would be shown in operation above ground, when there would be no difficulty in drilling a hole at the rate of 12 in. per min. in the same rock that was being worked in the heading, although the rate underground did not average more than 6 in. per min. Of course it was more difficult to bore the holes, as had to be done underground, at more than $\frac{3}{4}$ mile distance from the air-compressors and in a small wet heading, than it was at the surface where all was clean and dry, and the air compressors were close to the rock-drilling machine. The tunnel when completed would he hoped be a great benefit to that neighbourhood.

Mr. W. FROUDE wished to express the pleasure with which he had listened to this well-considered paper, and his appreciation of its value, showing as it did the great pains that had been taken in the investigation of the whole process which had been carried out. The machinery employed had been improved step by step, until it seemed to have arrived at a very perfect condition. He should be glad to know what was the quality of the steel used for the drills, and its hardness and temper; and under what conditions the drills were found to work most effectively.

Mr. GEACH replied that the steel used for the drills was crucible cast steel, the best that could be got; and the drills were tempered as hard as possible, to a dark straw colour.

The PRESIDENT enquired whether the machine described in the paper had been tried for boring in quartzite or in any other material harder than the Pennant rock in which the heading was being driven under the Severn.

Mr. GEACH said the machine had not been at present tried in any other rock; and the particulars given in the paper were those of the work actually done in driving the heading.

Mr. T. MORGANS observed that in the air compressor the steam and air cylinders were of the same diameter and stroke; and he should be glad to know what proportion the pressure of the compressed air bore to that of the steam. He also enquired whether there had been any experience with electrical blasting.

Mr. G. D. HUGHES asked what was the number of strokes of the drill per minute that had been found to have the greatest effect.

Mr. E. A. COWPER remarked that there were many rock-boring machines in use, some of which bored very rapidly, one he believed (Mr. Darlington's) working up to 800 strokes per min. He enquired what pressure was obtained with the air compressors described in the

paper, and what was the number of revolutions per min. at which they worked, and the quantity of air delivered by them.

Mr. Geach replied that in the air compressors the steam pressure employed was from 60 to 80 lb. per sq. in., cut off at about half stroke; and the steam cylinder being coupled at right angles to the air cylinder, the air was readily compressed up to 60 or 70 lb. per sq. in.; of course the mean pressure in the air cylinder would not be equal to that in the steam cylinder, because the air was taken in only at atmospheric pressure, even supposing the air cylinder was completely filled at the beginning of each stroke. As the stroke proceeded the pressure rose, the maximum pressure of 60 or 70 lb. being reached only in the latter part of the stroke. The speed of the air compressor to deliver the required quantity of air varied considerably with the state of repair it was in, the average speed being about 20 rev. per min. for supplying two drills; the air cylinders and pistons were found to wear much more rapidly than the steam cylinders, owing he supposed to the water and the air combined and to the dirt that got in; on this account the quantity of air discharged could not be calculated from the speed of the compressor, and could only be ascertained correctly by actual measurement. There had not been any trouble found from the valves at all. The only feature about the air compressor which was not shown in the drawings was the arrangement for charging the inlet openings with air by means of a blowing fan driven by the engine; he did not know whether that was novel, but it was new to himself; he had not put the fan on yet, because the machine as it now was gave more air than was at present required, so there was no occasion for it.

With regard to electric firing, he had tried it, but with very poor results so far. He had succeeded in firing all the holes at once, but had never found so much rock come away with simultaneous blasting as with the ordinary system of hand-blasting with fuses. He had expected the electrical blasting would be an improvement and would do better work, but the result was the reverse, and he could not account for this; by the hand system as at present used more rock was brought away with less dynamite than by the electric firing.

With regard to the number of strokes per min. made by the drill, of course that varied; it was difficult to count them, but the speed was perhaps 700, 800, or even 900 strokes per min. That was simply an approximate estimate, the only means of counting the strokes being by counting the revolutions of the drill itself. In reference to the wear of the revolving parts in the drill, he thought the same principle applied as in Mr. Webb's circular slide-valve, by the rotation of which the surfaces were stated to keep in perfect condition; and so he found with the interior of the drill cylinder, and he could not see a scratch upon it even when worn out; the partial rotation of the drill at each stroke he supposed kept the surfaces true.

The President observed that the rock-boring machine now described was rather a jumping than a drilling machine; the drill rotated between the blows, but the hole was made by jumping. In that respect it was like Captain Penrice's machine.

Mr. Geach said that was the case; and all the machines of that class were called drilling machines, but the action was jumping, although the drill did rotate between the blows; they all imitated manual action as nearly as possible. The only machine that acted as a true drill was the diamond borer of Major Beaumont, in which the hole was bored solely by the rotation of the drill under pressure, without any percussive action.

The President moved a vote of thanks to the author of the paper, and said he thought it desirable for the subject to be again brought forward for further discussion after the machine had been seen in operation. It was a very important subject, and he knew from his own experience that machines of this or an analogous kind were very much wanted at the present day. If it could be shown that the machine now described was superior to others, he had no doubt it would come extensively into use both in England and abroad.

The vote of thanks was passed.

The Meeting was then adjourned to the following day.

The Adjourned Meeting was held in the Assembly Room, Grand Hotel, Bristol, on Wednesday, 25th July, 1877; THOMAS HAWKSLEY, Esq., President, in the Chair.

The following paper was read:—

ON THE TYNEWYDD COLLIERY INUNDATION, WITH PARTICULARS OF THE APPLIANCES USED FOR RESCUING THE MINERS AND RECOVERING THE WORKINGS.

By Mr. T. HURRY RICHES, of Cardiff.

The Tynewydd Colliery, which is 98 yards deep to the landing, is worked upon the old-fashioned principle of "counterbalance by water"—having merely a flat drum sheave upon the pit framing, over which the chain rope runs; and to this sheave is attached the brake, worked by levers from the pit's mouth. It is a very primitive appliance, but this process of sending down water with each cradle will at once be seen to be most objectionable in connection with an inundation, as of course the water has again to be pumped up.

The coal worked in this pit is the "No. 3 Rhondda," and the mode of working is "pillar and stall." The seam dips in the locality of the points marked L and M in the plan, Fig. 1, Plate 37, at an inclination of about 1 in 10 towards the southwest, as shown by the section, Fig. 2. From this section it will be seen that Thomas Morgan's stall, where the entombed men were, which is 12 yards wide and 5 ft. 6 in. high, is driven 45 yards towards the rise from Jenkins' heading; therefore the floor of the upper end would be 13 ft. 1 in. vertically higher than the floor of the heading, and this fact made an air lock or chamber for the captives to escape to when the flood met them at J on the plan, and prevented their reaching the upper workings. The water was kept back by the compressed air in this stall to 35 yards from the face, this giving a vertical distance of 10 ft. 2 in. below the level of the floor at the top end. The pumps which were used in this pit prior to the late catastrophe were one ordinary 6 in. force pump for raising the water out of the lower workings into the upper level, whence it runs alongside the roadway

720 yards to the sump at the bottom of the shaft, and from thence is again raised by an ancient beam double pump, which is worked by a breast water-wheel 28 ft. diam. and 4 ft. 6 in. wide inside the buckets.

The water broke into the pit from the abandoned Cymmer workings through Oatridge's heading at H, Fig. 1, on the evening of Wednesday the 11th April 1877. The same night, very soon after the accident, several managers from neighbouring collieries, as also Mr. Galloway, deputy inspector of mines for the district, were on the spot; and consultations were held as to the best means of instituting search for the poor fellows who were known to be in the pit. Finally two additional pumps were borrowed from adjacent pits and put to work, raising from the lower levels into the upper, as it was then thought that the large double pump in the shaft would be able to take off all the water so raised.

As an auxiliary, if it should be required, a large "Special" pump was taken up from Cardiff on the 13th, to be used at the option of the managers; and the Taff Vale Railway Co. lent a locomotive engine, which was fitted for supplying steam to this pump when at the bottom of the shaft. The alterations in the locomotive were made under the writer's instructions, and consisted simply in taking out of the smokebox the bent steam-pipe which connects the steam-chest with the boiler, and putting on in place a strong flange, into which was screwed a $2\frac{1}{2}$ in. iron prepared tube, the end screwed with gas thread and coupled the same as ordinary gas piping. The locomotive was at once placed in one of the nearest sidings to the pit's mouth, but was not considered requisite until the 18th, when more urgent aid was called for. The steam pipe was at once carried down the shaft, its total length being 130 yards. The end was allowed to pass the pump by about 1 ft., terminating in a small drain cock to carry off the condensed steam; and the steam was taken at a branch about 1 ft. higher, which prevented any trouble from condensation. It was found, by means of the pressure gauges upon the locomotive and the pump steam-chest, that 8 lb. per sq. in. was lost in transit, the steam being supplied at 110 lb. per sq. in., and used at 102 lb.

The above-named were the only pumps used at Tynewydd Pit; but at Cymmer Pit a temporary arrangement was made for lifting out water by means of a large tub, which was used continuously until the water had been drawn below the level of that pit, Cymmer not being so deep as Tynewydd.

During the first night of the inundation, search was being made for the missing men; and after some hours' knocking, the explorers were answered by similar knockings from Morgan Morgan's stall, Fig. 2, Plate 37. Instantly men were started to cut through the pillar of coal which separated them from those they sought to release. They had only about 8 yards between them, and the prisoners were at once heard also working to meet them. After heroic labour, four men were safely brought out; but the other poor fellow, in ignorance of the action which compressed air would have when an outlet was given to it, persistently placed himself in the hole, and as soon as the pick struck through, the air forced him into the opening and killed him instantaneously.

Upon going into this stall after the men had been taken out, the rescuers realised the fact that other men were yet alive and knocking in that portion of the lower workings which was submerged. Owing to the height of the water, nothing could then be done, as it covered the face of the coal. Divers were then sent for, who used their best efforts to communicate with the entombed men, but in vain. Pumping was therefore the only resort until the coal could be got at; and it was continued henceforth with the greatest possible energy until the 16th, when the men were enabled to commence their final cutting in Glynog heading, Fig. 2. In beginning the work the men were standing in 19 inches of water, and they were obliged to cut the top coal only at first, so as to leave a barrier until the water was further reduced. This was most laborious work, for all the cut coal had to be lifted over the barrier; but on the evening of the following day the water had so far lowered that they were able to cut the barrier away, after which they worked heartily and made rapid progress.

There were however forty yards of coal yet intervening between them and their imprisoned comrades, and it was feared that starvation

would have done its work before they were reached. The writer therefore designed an apparatus for the purpose of boring through to communicate with the prisoners and to convey food to them, and he calculated being able to reach them in about four hours, while the heading would take fully as many days to drive through. This boring bar was a strong iron tube, the leading end being cut into the form of a crown escapement wheel, as shown in Fig. 6, Plate 38, with the teeth set alternately in and out, to give the necessary clearance to the bar. The outer end was fitted with two stopcocks, with a pressure gauge between the two, for ascertaining the pressure of air in the submerged stall, and so checking the levels taken by the surveyors. The apparatus was not permitted to work however until the day before the rescue, as it was preferred first to advance the heading until there were only two or three yards to bore through; and then the tube was driven through.

When the workers had cut through the coal to within about four yards of the stall which held the men, it was suggested to put up three pairs of doors in the rescue heading R, Fig. 2, for the purpose of stopping the escape of the compressed air, and to work as follows: one pair was to be fixed close to the face before breaking through to the men, the next pair to be fixed at the estimated water level in the pit, and the third pair 7 ft. above that level. The volunteer band of rescuers were to go inside the last-named doors, which were then to be securely fastened behind them. They were then to break through to the prisoners, and bring them up to these doors. This done, the two other pairs of doors were to be securely fastened, and the air allowed to escape from between the two outer pairs, and so enable the men to come out with perfect safety. This arrangement was however doomed to failure. The two outer pairs were fixed, and at the writer's suggestion the outermost pair was tested by pumping up the space between them and the face with two air pumps, which he had conveyed there for this purpose. Unfortunately more than 1½ lb. per sq. in. pressure could not be got, as the doors leaked. Prior to this, the boring tube had been driven through into the stall, and the pressure gauge attached to it showed 5 lb. per sq. in. existing inside. The idea had been to pump up the space between the doors and the

face to the same pressure, and so prevent the possibility of a recurrence of the fatal accident which had occurred in releasing the other men; but as the doors proved defective, the air pumps were kept going as hard as possible to supply the space, and so maintain the highest attainable pressure. The air doors were each 2 ft. 9 in. by 1 ft. 8 in., two being in each frame.

The first men who entered these doors so courageously, and worked so hard, found by and by that inflammable gas was collecting round them, and had to escape from the danger. After a short time a second detachment took turn, and the same process of active air-pumping was kept up; but they too were driven out by the same enemy. Many hours of continued water-pumping had however by this time reduced the water to within 15 in. above the floor at the top end of the entombed stall; so that, as it was found there would be fully 4 ft. clear above water level for the imprisoned men to live in, it was decided to let the remaining compressed air (which had been gradually reduced in pressure to $1\frac{1}{2}$ lb. per in. by allowing it to escape through the boring-tube cocks) be released altogether, and then to cut through without using the doors. This was done on Friday the 20th April, when the men were brought out, after the expenditure of immense energy, and, as is seen upon calm reflection, much misdirected exertion.

The Boring Apparatus, with the food carriages which were sent through it, is shown in Figs. 3 to 6, Plate 38, and will appear a very crude affair; but it must be remembered that it was schemed, made, and ready for work within twenty-four hours. The boring tube B was carried in the frames of an old crab winch A A, acting as a spindle for the driving pinion P, which was fixed upon it by a half-round taper key. The driving wheel W was allowed to slide upon its shaft S, which had a long key-groove, the key being secured in the wheel; upon the end of the shaft S the handle for driving was fixed. A centre nipple N was slipped into the outer end of the boring tube, against which a feed screw F acted to keep the cutter up to its work. The two stopcocks C C were placed 2 ft. apart, so as to allow the food carriage to be inserted between them. After the

carriage was put in, the outer cock was shut and the inner one opened; and as the tube had a downward inclination towards the stall of 1 in 10, as soon as the inner cock was opened the food carriage ran through. The pressure gauge G was attached between these two cocks.

The cutter end of the boring tube, Fig. 6, was made of best wrought-iron pipe; and after the teeth were cut and set, they were case-hardened with prussiate of potash and sal-ammoniac. From experiments which have since been made it is found that this apparatus can bore coal at the rate of 60 ft. per hour. The tubular drill that was employed is shown upon the table; also one of the food carriages that was used.

The pumps working in the drift were, one of Tangye's "Special" pumps, with a 10 in. water plunger, and capable of lifting 15,000 gallons per hour, but it did not work regularly, as those in the shaft could not take the water off so fast; and a second "Special" pump in addition to this, with 6 in. water cylinder, to raise 7,000 gallons per hour. Working in the shaft was the old beam pump, having two barrels, each 12 in. diam., with 3 ft. stroke, and making five strokes in each barrel per minute, which, taking the bucket as two-thirds full, would raise 5,890 gallons per hour. This pump worked from the time of inundation to the day of clearing, 456 hours, making a total of 2,686,000 gallons raised by it. In the shaft was another "Special" pump, capable of lifting 13,000 gallons per hour, which worked for 290 hours, raising a total of 3,770,000 gallons. It will thus be seen that 6,456,000 gallons of water were raised at Tynewydd Pit; in addition to which, the tub in Cymmer Pit was worked for 108 hours at 30 runs per hour, and a further 96 hours at 20 runs per hour, and each time brought up nearly 234 gallons, which will make a total of water raised at Cymmer equal to 1,203,900 gallons; thus giving the general total of water raised out of these inundated workings as 7,659,900 gallons, equal to 34,196 tons, raised from an average depth of 293 feet.

Mr. Riches exhibited the boring tube employed in the rescue, and also one of the food carriers, together with a working model of the boring apparatus.

The President remarked that he understood the boring apparatus had subsequently been employed at another colliery in Glamorganshire, and enquired what had been the results of its working there.

Mr. Riches replied that a few days after the boring apparatus was used at Tynewydd it had been borrowed by Mr. Daniel Thomas to bore in a heading which was being driven in a neighbouring colliery towards an old set of workings known to contain water; and that apparatus had continuously worked there ever since. Some slight alterations were being made in it, giving it a longer feed for the purpose of avoiding so frequently shifting the driving pinion back upon the boring tube, which at present had to be done after a traverse of less than 2 ft.; instead of this he was now preparing to put in a permanent tube of 6 ft. 8 in. length through the frame, with a feed screw of 4 ft. 6 in. length working inside the tube at the back end, so as to be able to give the boring tube a traverse of 4 ft. before inserting a fresh length, instead of the short traverse it now had; the spur wheel would then be fixed upon the driving shaft so as not to slide upon it, and the tube would have a feather along its whole length, for sliding through the pinion as it was advanced by the feed screw. This improvement was now being got ready.

Mr. E. A. Cowper wished to express the feeling of admiration, which was no doubt shared by every one, at the pluck exhibited on the occasion of the Tynewydd disaster by Mr. Riches and the others connected with him, which showed what Englishmen would do when they were put to it, to save their fellow-creatures' lives. The apparatus shown in the drawings seemed to be of a very ingenious character; it was an admirable application of the air-lock for the purpose. It seemed to him that if it was so valuable (and it would have been more valuable if it had been allowed to be used sooner) there ought

to be a regulation that every colliery should possess one. It might be put together in a few hours, and the expense of the whole thing would be but trifling; plenty of light tube could be had that would reach a long way—as far as 100 ft. if it were necessary to go as far as that. When a machine had been invented that was known to be useful for saving life, there was no reason why its use should not be insisted upon. No one would think of working a boiler without a safety valve, and he did not see why collieries should be worked without safety pipes to convey food and intelligence to men who might be imprisoned, and to drain off air or water; and there were several applications in which the machine would be useful. The details seemed to have been well considered; in this instance the machine was a rough and ready one, and future machines could be constructed in a somewhat more refined manner in reference to the feed motion and the stuffing-box. No doubt something could be contrived that would make the joint good against the face of the coal where the boring tube had to go through—perhaps an india-rubber sheet behind a flange on the pipe, as suggested by Mr. Upward, would be useful to prevent the leakage of air through the coal round about the tube, as the coal was very porous. He understood that the colliers could communicate with one another through the coal to a considerable distance: through as much as ten yards they could make themselves heard by shouting; so that where there was simply a wall of coal between the men and their rescuers, intelligence might be conveyed to them with very great advantage to the chances of getting them out, or supplying them with food. The boring apparatus described in the paper was of very simple description, and if the boring tube were made of steel it might be thinner, and the machine might be provided with a supply of sharp boring tubes ready for use.

Mr. J. J. GEACH observed that there were no means shown for withdrawing the core produced by the borer; and he enquired how the core was removed for allowing the food carrier to pass through the tube.

Mr. W. E. Rich remarked that, although the dial pressure-gauge shown in the drawing was doubtless almost the only one that was applicable under the circumstances, still it seemed rather a risk, considering how imperfect the graduations of pressure gauges of the Bourdon type generally were, to expose men's lives to the chances of its recording pressures accurately within a foot or two of water head, seeing that an extra 18 inches height of water might have been fatal. If a mercury gauge or a water gauge could be introduced in such a case, it would seem to be more prudent.

Mr. W. R. Browne enquired about the failure of the three doors constituting the air-lock in the rescue heading, which appeared to be attributed to their not being secure against the air pressure—whether that was considered to be a fault due to the hasty construction of the doors, or whether it was a fact that the coal was so jointy that the air escaped through it round the doors; and in either case what would be the best mode of procedure under similar circumstances on another occasion. On this occasion the fact appeared to be that the air-lock had not been used at all; and that, if the water had not been got down by the pumps to such a level that the imprisoned men had still some air left to breathe when the pressure within their stall was reduced to the same as the pressure outside, their rescue could not have been accomplished. That lowering of the water level by pumping might not be possible on another occasion; the amount of water to be raised might be greater, and the pumps might not be able to get it out in time. It seemed to him that the essential thing to be looked at was how a rescue could be effected under similar circumstances, in a case where it was not possible to allow the air to take its normal pressure; and what could be done in order to make the air-lock, which seemed to be an obvious device, a successful one. That seemed to him the most important lesson that could be derived from the very extraordinary circumstances to which attention had been called by the present paper.

Mr. E. B. Marten asked what had been the reason that the attempt to make use of diving apparatus had not been successful: was it

unsuccessful because of some defect in the apparatus, or because of the circumstances of the place?

Mr. E. A. COWPER, referring to the enquiry that had been made about the air-lock, mentioned that a mode had been devised by Mr. Upward of making an air-lock by means of a tube as much as 18 in. diameter and 6 ft. long or more, so that a man would be able to pass through, the joints with the coal being made good with india-rubber.

Mr. C. HAWKSLEY asked whether any means had been taken to prevent the escape of air round the boring bar, by the use of any kind of packing. As the cutters at the end of the boring bar were, he presumed, necessarily of greater diameter than the bar itself, the air would rush out through the annular space between the bar and the solid coal unless some means were taken to prevent its escape. From statements made at the time of the occurrence, he imagined that this was what really took place, for in order to prevent the escape of air the imprisoned men were said to have blocked up the end of the bar as soon as it broke through into their stall.

Mr. T. DYNE STEEL asked whether it was not the fact that the boring apparatus could not be used for the intended purpose of conveying food through to the men, in consequence of their covering the hole with their caps and jackets as soon as the borer made its appearance in the stall, not knowing what was the purpose intended. With regard to the diving apparatus, he was afraid a great deal of valuable time had been lost (which should have been devoted to pumping, the pumps having been necessarily stopped during the diving experiment) in getting the divers to attempt to go in, and he was at a loss to know what was intended to be accomplished by them; he feared that, if they had succeeded in reaching the men, their appearance would have frightened away the little life that was left in them.

Mr. T. MORGANS thought it was fortunate that the inclination of the boring tube through which the food carrier was intended to be

sent was downwards towards the imprisoned men; if it had been upwards he should be glad to know how the transmission of the food carriers would have been managed: some special contrivance must then have been necessary, as in the case of getting out the core if one were formed. He differed from Mr. Cowper with regard to making it obligatory upon all colliery proprietors to have one of these machines at hand; it might be a very desirable machine in cases where it was known that old workings were contiguous, supposed to be filled with water; but regulations were getting rather too paternal, he thought, in the matter of mining, in instructing proprietors what they should do and what they should not do; and he thought it was time that a little relaxation should be made in their favour, rather than that additional burdens should be put upon them. He did not see any object in insisting upon having one of these machines at every colliery, especially if the colliery was in virgin ground; there was not a difficulty to meet in such cases.

Mr. A. PAGET enquired what arrangement there had been, with the downward inclination of the boring tube in the present instance, for bringing back the empty food-carriers up hill from the imprisoned men. With regard to the remarks just made to the effect that legislation was getting a little too paternal in relation to collieries, he thought that, considering the extent of legislation respecting railways, and the number of deaths through accidents on railways and in collieries, a little more legislation with regard to collieries would not be amiss. The proposal of Mr. Cowper however might well be modified to the effect that each district should have a boring apparatus of this sort. As steam users were obliged to have safety valves to boilers, he thought that an apparatus of this kind would be very desirable for collieries, even though it might not be frequently used.

The PRESIDENT remarked it should not be omitted from consideration that safety valves were not generally put upon boilers by the operation of law, but from the necessity of the circumstances.

Mr. H. K. JORDAN considered that, although this was an ingenious apparatus for boring a hole through coal, yet from a mining point of view the boring of holes through coal to give colliers food was not a matter of primary importance. The matter of primary importance was to get the men extricated; and it appeared to him that if the very ingenious invention of Mr. Upward were adopted, with a tube of sufficient size to get the men through, the first requirement would be satisfied. It was clear that, whilst this machine was boring a small hole through the coal simply for the purpose of passing food, the whole of the other work of liberation would be stopped; but if a larger hole were bored, say 16 or 18 in. diameter as proposed by Mr. Upward, then a man might readily get through a hole of that size to the imprisoned men, so as to convey food or intelligence to them, and the men themselves might come out through a hole thus bored, and in this way be speedily liberated. He did not concur in the suggestion which had been made that one of these machines should be kept at every colliery, because that would only be inflicting needless expense upon the collieries: during his connection with mining he had only heard of two cases in England in which men had been imprisoned in this way; and to tax every colliery or every district in the kingdom in the manner proposed would be unnecessary. The boring apparatus he thought was a valuable adjunct; and if one were kept somewhere in the kingdom, so that it could be telegraphed for and received at any colliery at twelve hours' notice, it would be desirable. It might perhaps be well to have a couple of them in the country; but he did not think more were needed to meet the requirements.

Mr. P. BRAHAM remarked that the cost of the boring apparatus described in the paper had been spoken of as very trifling; but if the hole were to be bored large enough to admit a tube of 18 in. diameter, such as had been referred to, it would involve a very considerable extra cost, and a hole of that size would be hard to bore, requiring a very powerful machine to be employed.

Mr. RICHES, in reply to the enquiry about the escape of air round the boring tube, explained that in this instance the distance the borer

had to go through was less than three yards, and the way in which the escape of air round the tube was prevented was by lapping a piece of spun yarn round the tube, and screwing it tight into the hole; it was then found that there was no escape of air whatever.

As to drawing the core, the coal was so friable and the diameter of the boring tube so small that no continuous solid core was formed; and upon allowing a small portion of air to escape, it blew the small dust out, so that there was no difficulty in getting rid of it in that instance. Where the same apparatus had since been driving, the distance bored was 15 yards; and he understood from Mr. Thomas that the coal was reduced to such a fine dry powder by the boring that it really worked itself out along the revolving tube, which was slightly inclined upwards, and no difficulty had been found in that respect.

With regard to the pressure gauge and the use of another kind, the gauge employed was the most accurate one he had at his disposal at the time, otherwise he should have used the mercurial gauge or an aneroid. He had tested two of the gauges with a check gauge, and found that each indicated the same pressure. He had been very careful in getting two accurate gauges out of a large number that could be selected from, and it was found when the boring tube broke through into the stall that the difference in the height of the water as derived from the gauge and that actually existing was only about 4 in., which he thought was very satisfactory.

As to the air doors, the cause of their failure was simply that the frames were made to fit the sides of the heading, which he thought was a mistake; they should have been made something like 8 in. larger than the heading, so as to allow of cutting a recess and fitting the frame into it; then by drawing or wedging the frame up against a smooth face of the coal, and inserting an india-rubber sheet or similar packing, he thought the difficulty of leakage might have been overcome. In the rescue heading at Tynewydd however there had been nothing but loose clay—what the colliers termed "slurry"—to run in, mixed with the small coal, as a means of preventing the escape of air round the door frames. With carefully constructed appliances, he thought the erection of air doors might be successfully and thoroughly carried

out, and that there would be no difficulty whatever in getting men out in similar circumstances in future by having a very small amount of apparatus capable of being carried to wherever it might be required.

As to the cause of the divers' failure, it was considered by all who had to do with the rescue that the failure was principally due to the divers not having been used to underground work. The seam was a thin one, and in no cases were the roads more than 5 or 6 ft. high; the divers' dress was generally 6 ft. 6 in. high, so that the man had to go along almost doubled up under so low a roof, and had great difficulty in finding his way. The divers were all certainly very nervous about the matter; they did all that they were able, but if they had been trained to such work, and had been familiar with the obstructions in the road, of which there were several, he thought they would have effected the object of conveying food to the imprisoned men. At the same time he concurred with what had been said about the effect of the appearance of the divers upon the men: he had asked George Jenkins, one of the rescued men, what he would have done if he had seen the diver come into the stall, and he said, "I think, Sir, I should have driven my pick through him."

With regard to the large air-lock suggested by Mr. Upward, he thought there was one objection to it from the fact that it was rather a difficult matter to get anything like sufficiently extensive power down into a colliery; steam was out of the question, and compressed air alone could be used, but it was a difficult matter to get anything like a heavy pressure of air at a long distance from the supply source. An air-lock or tube 18 in. diameter would require a great amount of power to drive it through; in addition to which he thought it would take a much longer time to get through a given thickness of coal with so large a tube. A good boring machine, with good air doors, would he thought be a far more advantageous means of effecting the desired result. The boring tube employed at Tynewydd was by no means a perfect apparatus; it was simply a crude affair, but it had effected its purpose; beyond that, no merit was claimed for it. A small tube he thought would effect the desired purpose of sending food and messages to men who were imprisoned; it frequently happened that the pillars in a colliery were of considerable thickness, and even with the best

coal-cutting machines it would take several days to cut through one of them; but with a small tube a hole might be got through in a few hours.

As to the stopping of the hole by the colliers, it was the fact that, when the boring tube went through into the stall, the men pushed their caps into the hole, directly the air-cock was opened, stopping it as tightly as they could, but not sufficiently to prevent some escape of air, so that after a while he was able to ascertain the actual pressure of air in the stall. A second tube was afterwards pushed down through the same hole, and by keeping the cock shut in pushing the tube through, the men were prevented from hearing any rush of air, and being in darkness they were unable to find the tube; so that he was able to check the one pressure gauge by the other.

As to the mode of sending the food carriers through, supposing it had been necessary to work to the rise instead of to the fall, the air pump, which was afterwards applied as mentioned in the paper, he had taken there originally (not knowing the strike of the coal, whether it was up or down) for the purpose of coupling to the boring tube, and putting an india-rubber washer under the head of the little cap of the food carrier, so as to propel it through the tube by the pressure of the air behind it, if the inclination were upwards, or if it would not run freely enough down. As to the return of the food carriers, that was not provided for; a sufficient number of them were taken to supply the men with food enough until they could be released.

The President said he did not know which most to admire—the very able way in which this boring apparatus had been improvised under the pressure of the peculiar circumstances, because to improvise it required a great deal of coolness of mind, which under such circumstances very few people indeed could exercise, but which was evidently possessed by the author of the paper—or the courage with which the imprisoned men were, by means of this apparatus and by other efforts, rescued from their situation, under conditions which were quite as perilous to those who made the efforts as they were to the men who had to be rescued. He was sure the members would

give their cordial thanks to Mr. Riches for having brought this very interesting subject before the meeting; and he was very much pleased indeed that on this occasion they had heard so much about it.

The vote of thanks was passed.

The following paper was then read:—

ON A NEW DYNAMOMETER FOR MEASURING THE POWER DELIVERED TO THE SCREWS OF LARGE SHIPS.

By Mr. WILLIAM FROUDE, F.R.S., of Torquay.

In the preparation of the design of a Dynamometer calculated to test the Power delivered at the end of the Screw Shaft by large-sized Marine Engines—a duty assigned to the writer by the Admiralty,—the well-known Friction Brake, which he had in view when first entering on the enquiry, proved to involve greater difficulties than anticipated, and the result was to induce him to search for some essentially different point of departure; and in describing that which he was fortunate enough to discover, and in explaining the apparatus which embodies it, the disadvantages of the friction brake will be sufficiently explained.

In the friction-brake dynamometer the power delivered to a revolving shaft is measured by the rate at which a definite weight is being virtually lifted or virtually drawn up out of a well of indefinite depth; and the number of ft.-lbs. of work done per min. is the product of the circumference of the drum at the effective radius at which the weight is lifted, multiplied by the weight and by the number of rev. per min.; and the effect of a greater or less delivery of power will be a variation, not in the driving force, but in the speed of rotation. Simple, effective, and convenient as the arrangement is when employed on a small scale, it proves to involve serious difficulties when greatly magnified; of these the most intractable is the great amount of heat which is developed between the rubbing surfaces, when the horse-power is being counted by thousands instead of by tens; and it was chiefly in order to escape this difficulty that the writer sought some fresh modus operandi, and ultimately felt his way to the arrangement now to be described as a substitute.

Under this arrangement it will still happen that the engine in delivering its power will be virtually winding up a weight out of a well of indefinite depth; but the weight, instead of being constant and assigned, will vary with the speed of rotation, much in the same way as the resistance of the propeller itself does; and thus the work performed by the engine under trial will more closely resemble its natural work, though the same circumstance renders necessary an automatic method of recording the variations of the resistance (or of the weight that is in effect being lifted), which occurs during the trial.

The reaction, it will be seen, instead of arising from the continuous friction of two solid surfaces, will consist of a multitude of reactions supplied by the impact of a series of fluid jets or streams, which are maintained in a condition of intensified speed by a sort of turbine revolving within a casing filled with water, both the turbine and the casing being mounted on the end of the screw shaft in place of the screw, the turbine revolving while the casing is dynamometrically held stationary; the jets are alternately dashed forward from projections in the turbine against counter-projections in the interior of the casing, tending to impress forward rotation upon the casing, and are in turn dashed back from the projections in the casing against those in the turbine, tending to resist the turbine's rotation. The important point is, that the speed of the jets is intensified by the reactions to which they are thus alternately subjected; and thus in virtue of this circumstance a total reaction of very great magnitude is maintained within a casing of comparatively very limited dimensions.

The nature of this arrangement can perhaps be best described by a series of skeleton sketches. The full details, as shown in Figs. 1 to 3, Plates 39 and 40, will be subsequently explained.

In Fig. 4, Plate 40, A represents the screw-end of the screw shaft; B B shows in section what has been termed "the turbine;" it is a disc or circular plate, with a central boss, keyed to the screw shaft in place of the screw, and revolving with the shaft. The disc is not flat throughout its entire zone, being shaped into a channel of semi-oval section, which sweeps round the whole circumference concentrically with the axis. To give definiteness to the conception,

let it be imagined that, to deal with an engine of 2000 Ind. H. P., the diameter of the turbine-disc to the outer border of the channel is 5 ft.

In Fig. 5, Fig. 4 is repeated, and what has been called "the casing" is added, being indicated by the letters CC, DD, the former representing the front and the latter the back. The face is shaped into a channel, the counterpart of that in the turbine-disc, which it also fronts precisely, so that the two semi-oval channels in effect form one complete oval channel, though the two halves are in reality separated by an imaginary plane of division. The back of the casing embraces or includes the turbine entirely, but without touching it. The casing is also provided with a boss, which is an easy fit over that of the turbine; and thus the turbine carried by the shaft can revolve within the casing without touching it, while the casing itself is stationary; and one half of the oval channel is running round while the other half is at rest.

Thus far the two half channels have been regarded as open and unobstructed; they are however in fact each closed or cut across by a series of fixed diaphragms, a single one of which is shown in Fig. 6, as in its place in the turbine-channel. The diaphragms cut the channel, not perpendicularly, but obliquely, being semicircular in outline, so that when set obliquely their circular edges fit the oval bottom of the channel, while their diameters span the major axis of the oval. In Fig. 7 is shown in dotted lines one of the diaphragms seen end on, or edgeways, as it would appear in an edgeways view of the turbine if this were transparent. Each half channel has twelve of these diaphragms, and is thus divided into a series of cells, each of which, if viewed at right angles to one of the diaphragms, or what is the same thing, if shown in a section taken parallel to one of them, is semicircular in outline; and if thus viewed in connection with the cell which is for the moment opposite to it in the counterpart half channel, the two together make one complete cell with circular outline. Thus the whole oval channel may be regarded as a series of obliquely placed circular cells; and as the function of the turbine is to rotate while the casing remains at rest, one half of each cell is moving past the other half in such a manner that the moving half, if viewed from its stationary counterpart, would by

reason of the oblique direction of the diaphragms which form the cell sides appear to be advancing antagonistically towards it; indeed the motion virtually constitutes such an advance, because the bottom of each moving half cell is continually growing nearer to the bottom of the stationary half cell which it faces. The effectiveness of this combination to resist rotation will be seen to depend essentially on this quasi-antagonistic virtual approach of the moving to the stationary half cells.

The channel and the whole casing is filled with water, and the turbine is made to rotate as described. When the turbine is thus put in motion, the water contained in each of its half cells is urged outwards by centrifugal force; and in obeying this impulse it forces inwards the water contained in the half cells of the stationary casing, and thus a continuous current is established, outward in the turbine's half cells, inward in those of the casing.

The current, though it is in fact originated solely by centrifugal force, possesses, when once called into existence, a vitality and power of growth quite independent of centrifugal force, and dependent on what has been termed the virtually antagonistic attitude or motion of the two sets of diaphragms, and the cells of which they are the boundaries. The nature or the modus operandi of this power of current-growth, though intelligibly demonstrable, is somewhat intricate to trace; and as the existence and effectiveness of the power is abundantly proved by experiment, and as therefore the growth of the currents under the influence of the power may be provisionally admitted, the discussion of the principle on which the action depends is deferred to an appendix. It is only necessary to state here, as one of the results of the discussion, that, with any given speed of the turbine, the system of internal motions involves a "Potential" or definite speed-producing power, which will continue to increase the speed of the currents until the friction experienced by them in traversing the cells produces a resistance equal to the Potential. This frictional resistance, as well as the potential itself, are alike proportioned to the square of the speed of the turbine, and thus the resulting speed of current is directly proportional to the speed of the turbine simply.

The manner in which the currents, when established, produce the dynamometric reaction, can be traced very easily. The explanation already given of the internal form of the cells which the current traverses, shows that the volume of water which constitutes the current in each complete cell may be regarded as a circular plane or disc of water, rotating in its own plane between the diaphragms, which define the direction of the water disc and which are the boundaries of its thickness. It will be noticed that as the diaphragms radiate from the centre of the turbine and casing, the discs of water which they enclose will not be of parallel thickness throughout, the part furthest from the centre being thicker than that nearest to it; but if we assume that the breadth of the channel in the turbine, which the diaphragms close, is small compared with the distance of the channel from the centre of the turbine, and that the diaphragms are pretty close together, this inequality of thickness will be kept out of sight; and it will be convenient to treat the matter thus, though a little consideration shows that the circumstance does not really affect the result.

Each of these rotating circular water discs may now be clearly regarded as subdivisible into, or consisting of, a series of hoop-shaped pipes or tubes of infinitesimal thickness laid one within the other, and each filled with a stream of some appropriate speed, the sides of the pipes being merely imaginary boundaries; and the disc, made up of these streams, will constitute a sort of vortex. Now each vortex, in virtue of the centrifugal force which is continually tending to stretch it edgeways, pushes against its circumferential boundaries; and as these boundaries are in fact made up of the bottoms or circular outlines of the two half-cells occupied by the vortex (the one in the stationary casing, and the other in the rotating turbine), the resultant force, measured in the plane of rotation of the turbine, is constantly tending with a determinate force to stop the rotation of the turbine, and to create rotation in the casing.

A simple way of expressing the magnitude of this force is to regard it as due to the reversal, in each semi-revolution of the vortex (that is in the traverse of each half cell), of the aggregate momentum of the vortex streams, measured in the plane of rotation of the

turbine; for the streams which on entering the cell are flowing in one direction, are flowing in the opposite direction with precisely the same speed on leaving it, and the force due to the reversal is directly proportionate to the amount of momentum reversed per second. This is as the product of the mass acted on per second and the change of speed imparted to it in the plane of rotation of the turbine; the change of speed is plainly twice the speed of the turbine; and the mass acted on per second is as the mean speed of the vortex current, which, as has been already explained, bears a constant relation to the speed of the turbine: so that the tendency of each vortex to stop the rotation of the turbine, and to give rotation to the casing, is as the square of the speed of the turbine.

The element of reaction just described would continue to act for a while, even if the turbine were suddenly brought to rest; for the vortical rotation to which it is due would continue, though with gradually diminishing speed, until it was extinguished by friction. But there remains another element of reaction to be taken account of, which exists only while the turbine is in rotation.

This is due to the circumstance that the imaginary hoop-shaped streams, of which each vortex is made up, are perpetually being severed or "sheared" by the passage of the planes of the turbine diaphragms past those of the casing diaphragms. The action here referred to does not interrupt or alter the effective speed of the streams thus displaced, for these, in virtue of the incompressibility of water, must each traverse its imaginary pipe everywhere with the same speed; but in virtue of the action, the particles which constitute each stream must, at the points of shearing, be perpetually undergoing alternate changes of speed, backwards and forwards in the plane of rotation of the turbine. For as they pass from the stationary casing cells to the rotating turbine cells, they are obliged to assume the speed of the turbine in its plane of rotation, and they thus react on the turbine diaphragms with a definite force, due to the amount of momentum per second imparted to them in transition; and again, as they pass from the rotating turbine cells to the stationary casing cells, they are obliged to lose that speed in the plane of the turbine's rotation, and they thus act on the casing cells,

tending to push them forward, with the same force with which their reaction, just described, tended to push back or stop the rotation of the turbine cells. The force is the same, because the same mass per second is acted on in both instances, and the same speed is in the one instance imparted, in the other instance taken away.

Here also it is clear that the reaction is as the square of the speed of turbine rotation, since the momentum generated per second (on which the reaction depends) is as the product of the mass operated on per second and the speed imparted to it; now the speed imparted is simply the speed of the turbine, and the mass operated on is as the speed of vortical rotation, which, as already explained, is necessarily as the speed of the turbine.

Having now traced the modus operandi by which the reaction is produced, and having seen that with an instrument of given dimensions the reaction will be as the square of the speed of rotation of the shaft to which it is attached, it is necessary to show that (1) an adequate amount of total reaction can be produced by an instrument of conveniently limited dimensions; and that (2) an instrument of given dimensions is governable as regards its reactions, that is to say is capable of being made to produce at pleasure a greater or less reaction with a given number of revolutions, so that within reasonable limits the same instrument is capable of dealing with engines of great or small power, allowing each to make its proper number of revolutions.

As regards condition No. 1, the theory shows, as will appear in the appendix, that, comparing two strictly similar but differently dimensioned instruments, their respective "moments of reaction," with the same speed of rotation in each, should be as the fifth powers of their respective dimensions. This proposition is fully borne out by experiment. The writer has had a pair of similar instruments made, in which the turbine diameters are respectively 12 in. and 9·1 in. Now $\left(\frac{12}{9\cdot1}\right)^5 = 4$, and accordingly the ratio of the moments of the two instruments at a given speed of turbine rotation should also have been 4. The ratio was in fact 3·86; but the small difference is referable to the circumstance that in the larger of the two

instruments the internal surface was rather less smooth and the friction of the water consequently rather greater than in the other. The data thus obtained not only verify the scale of comparison based on the 5th power of the dimension, but they also furnish a starting point by which to quantify the dimensions of the instrument which will be required to deal with any given horse-power, delivered with a certain number of revolutions per minute; and it thus appears that to command the measurement of 2000 H. P. delivered with 90 revolutions per minute (a fairly typical speed for the power), an instrument of the dimensions shown in Figs. 1 to 3, Plates 39 and 40, will suffice: the turbine being 5 ft. in diameter, and being in fact a duplicate turbine, or formed with two faces, with a double-sided casing to match. This two-faced arrangement, it may be added, while it supplies a double circumferential reaction with a given diameter, has the advantage of obliterating all mutual thrust on the working parts: the centrifugal forces of the double set of vortices pressing with equal intensity on the two internal opposite faces of the rigid casing.

As regards condition No. 2, the theory suggests that, by contracting the internal waterways, that is to say the passages through the cells in the turbine and the casing, and thus intercepting the free vortical rotation, all other things remaining the same, the moment of reaction due to a given speed of rotation could be greatly reduced. The experiments with the models fully bore out this anticipation also, and proved that, by the very simple arrangement shown in Figs. 1 and 3, the reaction with any given speed of turbine rotation can be reduced with a perfectly graduated progression in any required ratio down to 1-14th; the object being effected by advancing, from recesses in the casing, abreast of the two opposite quadrants in each turbine, a lunette-shaped sliding shutter E of thin metal, so fitted as to be carried forward (by a screw motion governed from the outside) along the divisional plane between the turbine cells and the casing cells. The intensity of the reaction is thus brought completely and easily under command; and in virtue of it, it follows that the instrument represented in the drawings, which as already stated is capable of dealing with an engine of 2000 H. P. making 90 rev.

per min., is also capable of dealing with one of only 340 H. P. making 120 rev. per min. And as it happens that, as already mentioned, the reaction of the instrument varies as the square of its speed of rotation, and the horse power delivered through it consequently varies as the cube of the speed of rotation (that is to say with a given setting of the shutters)—and as moreover this law of variation is somewhat the same as that which the engine itself experiences when propelling the ship under natural conditions—it follows that the same setting of the shutters which suits a given engine when working with its highest speed and power will also approximately suit it when eased down to its lowest.

It seems therefore that, alike as to the dimension of instrument suited to engines of very high power, and as to the adaptability of a given instrument to engines of greatly varied power, the requisite conditions are satisfactorily fulfilled.

The discussion thus far has dealt only with the hydrodynamical reaction which the combination involves, and in a theoretical point of view this is sufficient; but as the practical application of the instrument plainly involves some ordinary mechanical reaction, due to friction in its working parts, it is well to point out that this, while it is of relatively small amount, is in effect wholly incorporated with the hydrodynamical reaction, and will thus be legitimately taken account of; in fact the frictional reaction on the screw shaft will be precisely equalled by the action on the casing.

Having thus shown how the moment of rotation of the screw shaft is wholly communicated to the casing, which is to be dynamometrically prevented from rotating, and is thus to subject the engine to a restraint equivalent to that of obliging it to wind up a weight out of a well of indefinite depth, it remains to be explained in detail how it is proposed to carry out the operation in dealing with any given ship.

In the first place, in order to render it easy to connect the instrument with any given screw shaft, the boss of the turbine must be bored out to a diameter considerably larger than that of the largest shaft to which it can have to be applied; and, to fit it to a given shaft,

an internal collar or "adapter" must be prepared, which will fit externally the interior of the turbine boss and internally the exterior of the screw shaft; and a proper keyway will be required for each fitting. The turbine thus mounted will "run true" on the screw shaft.

The ship, before she leaves the dock for the trial of her machinery, will have the instrument mounted as described, in place of her screw, as shown in Fig. 9, Plate 41. The casing will be provided with proper apertures, capable of being closed at will, to permit the egress of air and the ingress of water as the dock fills. The casing will thus be in a condition to receive the moment of rotation delivered by the screw, and to communicate it to the recording apparatus.

If the "moment" to be recorded is regarded as a product of two factors, "force" and "leverage," of which (that the product may have its proper value at each instant) the one must vary inversely as the other, it is plainly a question to be settled by considerations of convenience, whether the record shall take the shape of a large force delivered at short leverage, or vice versâ; and on examination it is quickly seen that the force-factor will prove inconveniently large, if taken account of at the circumference of the casing, and that it is desirable for several reasons that it should be obliged to develop itself at a leverage enlarged to many times the radius of the casing.

The assumed maximum which the instrument shown in the drawings was calculated to deal with, was stated to be 2000 H. P. delivered at 90 rev. per min.; and a moment's calculation shows that this, if taken account of at the circumference of the casing, say at 3 ft. from the centre of the screw shaft, would take the shape of a circumferential strain of just 17·4 tons,* a force which plainly will bear large reduction; and it is proposed to effect this by the arrangement shown in Fig. 9, Plate 41, which, by lengthening the leverage in the ratio of 10 to 1, reduces the force in the same proportion.

The lever here shown is a triangular combination, of which the diameter of the casing C C armed with proper projections forms the

* $\frac{33{,}000 \text{ ft.-lbs.}}{6 \text{ ft. diam.} \times 3{\cdot}1416} \times \frac{2000 \text{ H. P.}}{90 \text{ rev. p. min.}} = 38{,}904 \text{ lbs.} = 17{\cdot}4 \text{ tons.}$

base, while the two sides, the upper one of which will be always in compression and the under one always in tension, are respectively formed of a spar F and of wire rope G. When the screw shaft is rotating, the compression and tension of the sides will thus be just 8·7 tons, and the downward force at the apex H of the triangle will be 1·74 tons or 3890 lb.

The lever will be fixed to the casing before the dock is filled, and its construction is such that it can be "slewed" and "topped" under the ship's quarter so as to swing clear of the dock walls. The ship thus fitted will be brought alongside some quay wall of one of the floating basins, where the recording apparatus R, Fig. 9, will have been already placed, projecting a few feet over the wall and carried on strong cantilevers or brackets; and she will be secured head and stern so as to prevent fore-and-aft movement, and will be boomed off to a proper distance from the apparatus.

The arrangement of the dynamometric apparatus presents no difficulty. The form shown in Figs. 10 to 12, Plate 42, has been pretty carefully considered, and though of course open to improvement, it would, the writer is confident, answer its purpose as it stands. In this, the downward pull delivered at K by the lever operates vertically on the middle of a flat horizontal steel spring S S, which is supported at both ends; and it is proposed so to proportion the spring that its maximum deflection shall be about $1\frac{1}{2}$ inches. Different springs however would be required for engines if of widely different power.*

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* If p denote the downward pull in lbs., delivered by the lever to the dynamometer spring, and H denote the horse-power delivered by the engine at n rev. per min. of the screw shaft, then $p = \frac{33,000}{10 \times 6 \times 3\cdot1416} \times \frac{H}{n} = 175\cdot07 \times \frac{H}{n}$. Thus with 2000 H. P. at 90 rev. per min., $p = 3890$ lb., for which a spring having a scale of 2600 lb. per inch of deflection would be used, giving a maximum deflection for the spring of about $1\frac{1}{2}$ inches. With 1000 H.P. at 100 rev. per min., $p = 1750$ lb., for which a spring having a scale of 1200 lb. per inch of deflection would be used. With 550 H. P. at 120 rev. per min., $p = 802$ lb., for which a spring having a scale of 530 lb. per inch of deflection would be used, so as to give still the same maximum deflection for the spring, namely about $1\frac{1}{2}$ inches.

Immediately over the spring will stand a light framework, carrying two independent types of recording gear, both of which will however be actuated by the upper end of one and the same "feeler" or sliding vertical rod I, Fig. 10, which will convey to them the vertical elastication of the middle point of the spring, on which point its foot rests.

In type No. 1, the "feeler" will govern the position of an "integrating wheel" J, Fig. 10, working on the face of a rotating disc, somewhat in the manner of Ashton and Storey's continuous steam indicator. The rotation of the disc will be made proportionate to that of the screw shaft, being communicated by a telescopic universal-jointed spindle L, Fig. 9, which takes its motion from the shaft by bevil gearing, Figs. 1 and 3. When there is no stress on the lever, and no deflection of the spring, the integrating wheel will be adjusted to touch the disc at its centre, and thus will receive no rotation, and its count will be zero, whatever be the speed of rotation of the disc. When the spring is strained by the lever, the departure of the integrating wheel from the disc centre will be proportioned to the strain, and its rotation and its count will be the product of the strain and the rotation speed of the disc, or, in other words, the product of the moment impressed by the screw shaft on the casing and the speed of the screw shaft: that is, the work done by the shaft.

In type No. 2, the duty of the "feeler" I, Fig. 10, is to actuate the horizontal arm of a light bell-crank M, the vertical arm of which, by means of a long horizontal connecting-rod N, carries a pen freely along a horizontal straight line, while a sheet of continuous paper P is independently moved under the pen across the line of its travel. The motion of the paper, like that of the rotating disc just described, will be derived from the rotation of the screw shaft. A stationary companion pen will trace on the paper a straight line as a record of that which the moving pen would trace if the spring remained unstrained, and will thus serve as a zero of force. The moving pen will thus trace a diagram, the ordinate of which is at each instant a measure of the strain on the spring, and the area of which, like the count of the integrating wheel, is the product of the moment on the casing and the speed of the screw shaft: that is, as before, the work delivered by the screw shaft.

The scales of both indications may be arranged at pleasure: in type No. 1 by the speeding of the disc and the diameter of the counting wheel; in type No. 2 by the speeding of the paper and the proportion between the horizontal and vertical arms of the bell-crank: each when duly interpreted will be a record of the effective work delivered at the shaft end by the engine, revolution by revolution, and each will thus serve as a check upon the other. Each when connected with a time record, which may be done automatically, will be converted from a record of "work done" into a record of "horse power."

In order that the indications of the feeler may represent with strict accuracy the elastications of the spring, and nothing else (for instance, that they may be independent of the deflections of the heavy framework which carries the spring, and of the slings by which it is supported), the light framework T, Fig. 10, which carries the integrating apparatus, and serves as the gauge from which the deflections of the spring are measured, will have its footing, not on the main frame, but on the spring itself immediately over its points of support. Thus, as the light framework T is itself subject to no strain, and may be made extremely rigid in the manner shown in the drawing, the apparatus will precisely record the motions of the spring alone, however the main frame &c. may be strained.

The connections of the dynamometer spring, with its framework on the one hand and with the lever on the other, are all arranged with mechanical details, such as to eliminate the effects of oblique stress, should any be introduced, by slight motions of the ship.

The whole dynamometric apparatus would be covered by a light shed R, Fig. 9; it would be carried by a pair of strong balks, by which it would be "bracketed out" to a proper distance beyond the face of the quay wall; and the inner ends of the balks would be loaded down by ballast. The balks might be framed together, and might be carried by wheels, which would render it easy to remove the apparatus complete into store when not in use, and to transport it to any point on the quay wall at which it might be most convenient to bring it into operation.

While a dynamometric trial is in progress, a series of indicator diagrams should be taken at short intervals of time; a comparison

between the indicated H. P. as determined by these, and the delivered H. P. as determined by the dynamometer, would show how much power is wasted in the working of the machinery between the cylinders and the end of the screw shaft. The waste thus measured would be on precisely the same footing as that which would subsist while the engines were propelling the ship under the same indicated H. P., except as regards two particulars: (1) the friction due to the thrust of the screw; (2) the difference of friction in the bearings which carry the screw shaft, between that due to the weight of the screw on the one hand, and on the other to the weight of the turbine and casing substituted for the screw, coupled with the side strain of the lever, which, whatever it be, is a lifting strain, tending to diminish the effective weight of the turbine and casing just mentioned. It will not be difficult to apply a calculated correction to the effect of both these circumstances.

Reference has previously been made to the amount of heat developed by friction in the friction brake, as probably the most formidable of the objections to its employment when the horse power to be dealt with is as large as that now contemplated. But it must not be supposed that the absorption of the same amount of work in the instrument that has been described will fail to be converted into the same amount of heat here also. The dynamic theory of heat is believed unquestionable as a theory, and the quantitative relation of work and heat is known with certainty within far narrower limits than deserve even to be mentioned in reference to the present subject. Although however the extinction of say 2000 H. P. will in fact here, as well as in the friction brake, consist in its conversion into so many units of heat, the circumstances of the conversion are entirely different in the two cases, and the difference is such as to obliterate here the inconvenience which was fatally great there. There, the heat was to be dealt with as being constantly developed between surfaces in close contact and inaccessible to water. Here, it will be making its appearance in the body of a mass of water; and though the rapidity of the development will be so great that the whole contents of the casing would be quickly raised to boiling point if the

heat had no escape, yet, in the first place, there is a considerable refrigerating power always at work, since the whole casing is enveloped in cold water; and moreover there is no difficulty in creating a constant change of water within the casing, sufficient to keep down the mean internal temperature to any limit which may be thought proper. For instance, when the instrument is dealing with 2000 H. P., the temperature would be kept well below the boiling point if in each minute 8 cub. ft. of cold water were substituted for the same quantity of the hot contents of the casing; nor would the exactness of the dynamometric action be in the smallest degree impaired by the substitution.

It is perhaps superfluous to recapitulate in detail the advantages which would be derived from the system of subjecting marine engines to dynamometric trial; but they may be summarised briefly. It is certain that a very large but unmeasured amount of power is wasted in friction and otherwise, between the cylinders and the propeller; and that the amount probably differs, both in respect of difference in type of engine, and in respect of goodness of construction and workmanship. The chief difficulties which thus arise are as follows:—

(1) The speed attained by a given ship, driven by a given indicated horse power, fails to measure discriminatively the merits of the ship.

(2) No means exist of ascertaining which type of engine delivers the largest proportion of the power that it indicates.

(3) No test exists by which it is possible to measure concisely the specific constructional merit of this or that engine, or to determine the relative constructional merit of the engines supplied by different firms.

The dynamometric test would remove at once each of these difficulties, by substituting a final and real test for a collateral and to a large extent a delusive one. For to rely exclusively on the test furnished by the indicator is almost equivalent to testing the power of a horse solely by the quantity of food he consumes and digests, or the efficiency of a boiler solely by the quantity of coal per hour it will legitimately consume on its firebars.

APPENDIX
EXPLANATORY OF THE DYNAMICAL PRINCIPLES OF THE TURBINE DYNAMOMETER.

To trace the dynamic actions which are correlative to the internal fluid motions described, it will be convenient to recur to the notion of the discs of water, which, rotating between the diaphragm planes, constitute the reacting vortices; and, as already suggested, it is convenient to regard the channel as virtually straight and of unlimited length, or (what is equivalent to this) forming a circle of unlimited diameter.

Remembering that the cross section of the channel is elliptical in order that the obliquely placed diaphragms which span it may be semicircular, each of these vortex discs may in imagination be subdivided by a series of quasi-elliptical layers or skins, laid conformably to the inner surface of the channel, and obliquely intersected by a series of planes laid parallel to the diaphragms; and if we assume these surfaces to be rigid but without thickness, and frictionless, we shall in the whole conception have substituted for a single complex idea the multiple of a simple one, which is nevertheless so nearly identical with it in effect, that in tracing out the abstract principles involved, we may clearly use the conception as the basis of our reasoning.

Under this conception, the spaces between every pair of diaphragms in the turbine, as well as those in the casing—that is to say the vortex spaces—would be regarded as completely occupied by a honeycomb system of pipes, of parallelogram section, and of a semicircular outline when referred to the planes of the diaphragms, laid obliquely so as precisely to fit the semi-elliptic channel, the mouths of the pipes, at each end of the semicircles in the casing, looking across the divisional plane into the mouths of the corresponding pipes in the turbine, and vice versâ. Though these pipes are imaginary, they will be spoken of as if they had a real existence, in order to define the stream lines.

When the turbine is at rest, each of the pipes which cross its channel in the manner described, taken in connection with its counterpart in the casing, may be regarded as capable of carrying a complete circular ring of water, flowing round this single circuit, with uniform speed throughout the circumference of the circle; but in this case the speed in any one pipe is not affected by the speed in any other, and the flow in each may in imagination have a different speed.

When the turbine is in motion, it no longer happens (as happened while it was at rest) that each individual pipe, say in the casing, is delivering back its water into the reverse end of the counterpart turbine-pipe from which it was received, thus forming an independent ring, but the water received from one pipe is presently discharged into the mouth of some other with which it happens to be brought into connection by the motion of the turbine; so that the complete series of pipes in any one layer, constitutes in effect one single circuit or quasi-spiral stream, threading its way round and round the whole circuit of the channel again and again, and so strictly continuous that the flow through every inch of it must have the same speed,—not the same speed in space—for owing to the circumstance that the pipes in the casing are stationary while those in the turbine are moving forward, the flow through the latter must have the greater speed in space—but the same speed relatively to the surface of the pipe within which it is flowing.

It will quickly be seen that the whole of the actions and reactions involved in the existence of the flow and essential to its maintenance, may be taken complete account of in terms of the conditions of the flow at the points of discharge and reception, or as it may be called, the "region of transference;" transference, that is, from the turbine to the casing, and vice versâ. It may be added that since the motions of the turbine and the casing are, relatively to each other, precisely the same in both regions of transference—the same where the water leaves the turbine and enters the casing, as where it leaves the casing and enters the turbine—all the relative reactions which occur in the one instance will be repeated identically in the other. Precisely the same conditions operate in both instances; and we now proceed to trace out these conditions.

Fig. 1, Plate 43, shows a segment of the outside layer of pipes, as they would appear at the region of transference if viewed through the sides of the channel, the planes in which they are bent being presented edgeways to the observer. The line A B is the equatorial or divisional plane between the turbine and the casing, seen edgeways. The oblique parallel lines show the oblique pipes; those above A B being assumed to belong to the casing, those below it to the turbine, taken at a moment when the mouths of the two sets of pipes are precisely in apposition.

It will be assumed that a steady speed of rotation is maintained in the turbine on its axis, and that the speed has been maintained long enough to have produced a steady speed of flow through the pipes; that speed, namely, at which the natural frictional resistance of the flow, equals the Potential or forward force inherent in the dynamic conditions. The direction of the motion of the turbine, and that of the flow of the streams, are indicated by the two arrows.

Let the speed of the turbine, and that of the flow relatively to the pipes, be respectively represented, both as regards magnitude and direction, by the lines $a\ b$, b C in Fig. 2; then the compound speed of the particles, that is, their actual speed in space as they issue from the turbine pipes, is shown by the dotted line a C. It will be convenient to call the speed and direction of the streams as indicated by b C, their "established speed" and "established direction;" and as indicated by a C, their "augmented" or "compound speed," and "compound direction." These speeds $a\ b$, b C, and a C, will subsequently be denoted by the letters V, v_0, and v_1, respectively. It is geometrically obvious that, measured relatively to their compound direction, the streams all become diminished in width or in sectional area, precisely as their speed is augmented; and again, that on entering the stationary pipes, the streams are obliged by their surroundings, as we have already seen, to resume at once their "established direction" and their "established speed," widening at the same time from their narrowed to their established width, in correspondence with their loss of speed.

The enforced extinction of the speed-augment at this "region of transference" is of necessity accompanied by an exaltation of pressure in the mouths of the recipient pipes, and the enforced change in direction of flow, involves a definite forward force on the sides of the recipient pipes which cause the deflection. This local augmentation of pressure, being satisfied in one direction by the retardation it imposes on the particles which are approaching it from behind, satisfies itself in the other direction, by acting as a definite force, urging forward the flow of the streams, and maintaining their speed in spite of frictional resistance; and thus constitutes what has been termed the Potential.

To give a maximum effectiveness to these dynamic operations, and to aid in calculating their nature, let us suppose the ends or mouths of the recipient pipes to be bent or canted so that their direction shall be coincident with that of the streams which impinge on them;* to be altered in fact from the arrangement represented in Fig. 1, to that given on a magnified scale in Fig. 3, in which the same reference letters are given, and a C represents as before, the compound direction of the outflowing streams with their augmented speed. Here the bending or canting of the recipient pipes along the line A′ B′, so as to coincide in direction with a C, reduces their sectional area in precisely such a manner as to make it fit that of the high-speed streams they are receiving; and the reduction of speed, and increase of pressure, and change of direction, occur at the inner end of the bent portion where the pipe resumes its established direction and area, that is to say they occur wholly within each pipe as a single structure, and in such a manner as not to produce any reflex effect on the pipes from which they issued.

If the flow through the pipes were frictionless, the augmented speed of stream would, on stream-line principles, be maintained throughout each pipe to the point of outlet at the outlet end of

* It will probably be advisable in fact to shape the diaphragm edges on this principle at the regions of reception; for there is reason to think that for want of this arrangement a certain amount of stream-line energy will, in the act of transference, be degraded into frictional eddy.

the semicircle, were the outlet free; or, since the system of pipes forms a continuous circuit so that the outlet is in fact not free, there would be a tendency to unlimited acceleration throughout the system. But in fact the acceleration will cease when the speed has become such that the frictional resistance of the flow has grown to an equality with the Potential, whatever the measure of that may be.

The problem then, reduced to its essential features, may be stated as follows. A stream with the speed v_1 (in feet per second), which corresponds with what has been termed the augmented speed, and under zero pressure or atmospheric pressure, enters the bent pipe $a\,b$ (Fig. 4, Plate 43), with a definite direction, and completely filling the pipe entrance at $a\,a'$; in passing the enlargement between $a\,a'$ and $c\,c'$ it assumes the reduced speed v_0, which corresponds with what has been termed the established speed, and which is less than v_1 in the inverse ratio of the pipe areas at the two positions; and flowing with that reduced speed through the enlarged pipe and experiencing frictional resistance in its flow, it issues at $b\,b'$, in a direction different from that in which it entered, and having again assumed the atmospheric pressure. The questions to be answered are, (first) What external or displacing force does the stream exert on the pipe? and (second) Into what internal force tending to overcome the friction of the flow, is the suppressed speed, $v_1 - v_0$, transmuted? The two branches of the question may be answered independently.

First. As regards the external or displacing force, each end of the stream will exert an appropriate push on the pipe; that at the entrance "directly" or forwards, that at the outlet "inversely" or by reaction, backwards, that is to say in the axial lines of the initial and terminal flow respectively, with a force the equivalent of the momentum per second received by the pipe at the entrance, and delivered by it at the outlet; in other words, if W be the weight (in lbs.) of water passing per second (the same of course at the points of the inlet and of the discharge), the respective equivalent forces are $\frac{Wv_1}{g}$ and $\frac{Wv_0}{g}$; the total displacing force experienced by the pipe, being, in respect alike of magnitude and direction, the

resultant of these two forces. The expression here given for each force is exactly equivalent to another well-known measure of the force embodied in the impulse or the reaction of a jet or stream, namely the pressure of a column of the fluid, the height of which is that due to the speed, acting on twice the area of the aperture.

Second. As regards the internal propulsive force, or the "Potential", which maintains the speed of flow in spite of friction, it is well known that if the pressure of the water per unit area, be zero at the point of greatest contraction and of highest speed, say v_1, and that if P_1 be the pressure due to, or which would generate, a flow of that speed, then where the stream has become enlarged so that its speed is reduced to zero, the water will have assumed the pressure P_1; if, however, the enlargement be only such that the speed is reduced (not to zero but) to v_0, the pressure will have increased (not to P_1 but) to a pressure (say P) which falls short of P_1 by the pressure (say P_0) due to, or which is required to produce, the reduced speed v_0, and bearing to P_1 the ratio of v_0^2 to v_1^2, in fact $= P_1 \frac{v_0^2}{v_1^2}$ so that $P = P_1 - P_0 = P_1 \left(1 - \frac{v_0^2}{v_1^2}\right)$. Now as the water will have resumed the zero pressure on reaching the outlet, the Potential is the pressure P acting on the whole sectional area of the pipe as enlarged (say) from a_1 to a_0; and if we call it F we have $F = P\, a_0$ $= P_1 \left(1 - \frac{v_0^2}{v_1^2}\right) a_0$.

The two results here arrived at are readily applicable to the conditions of flow which exist in the pipes into which we have assumed the vortices to be subdivided, and they thus supply an elementary measure of the force exerted by the turbine on the casing; and they would furnish a complete or integral measure of the whole force, if we could assign truly the law of the friction, to which each of the imaginary streams is in fact subject. Indeed if each of the streams were enclosed in an actual pipe we could approximately assign such a law: but the multiplication of surface would involve, on the whole, an inadmissible amount of friction, and under the real circumstances of the flow, the mutual friction of the streams against

each other is so complicated by their becoming intermixed by eddies, that a complete solution is probably unattainable.

A provisional solution however is attainable, in relation to any given layer of streams at a given distance from the vortex-centre, (say for the outermost layer) by assigning an arbitrary value to the friction, assuming it however to be approximately as the square of the speed of flow.

Reverting to Figs. 2 and 3, the symbols used in Fig. 5 become readily translatable. The line $b\ c$ represents v_0, or the speed of the established flow, $a\ c$ represents v_1 or the augmented speed, and $a\ b$ represents the speed of the turbine, say V. Call the angle $b\ c\ d = \beta_0$ and $a\ c\ d = \beta_1$. It has already been pointed out that the additional slant $(\beta_1 - \beta_0)$ given to the mouths of the pipes to meet the inflow of the stream with the augmented speed, has the effect of narrowing the passage so as to give it a sectional area corresponding with the speed. Taking the case of any single pipe in the layer under these conditions, in the first place the weight of flow per time-unit, whether with the established or with the augmented speed, is precisely the same; so that if we call this W, and if w be the weight of one unit volume of water, and a_1, a_0 the sectional areas of the passages corresponding with v_1 and v_0 respectively, we have $W = w\ v_0\ a_0 = w\ v_1\ a_1$. Hence the momentum per unit of the stream entering with the speed $v_1 = W\ v_1$, that of the outflowing stream with the speed $v_0 = W v_0$; and the sum of the forces due to the maintenance of their momenta, taking only their components in the line of motion of the turbine, is—

$$\Phi = \frac{W}{g}(v_1 \sin \beta_1 + v_0 \sin \beta_0)$$

$$= \frac{W}{g}(V + 2v_0 \sin \beta_0) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

since $v_1 \sin \beta_1 = V + v_0 \sin \beta_0$.

As regards the Potential or force available for acceleration in the first instance, and for overcoming the fluid friction due to the steady speed when this is attained, we have already seen that its value is

$$F = P_1\left(1 - \frac{v_0^2}{v_1^2}\right) a_0$$

But P_1 is the fluid pressure per unit area due to fluid speed v_1, or is

that due to a head, (h) such that $h = \frac{v_1^2}{2g}$; and since $w\,a_0\,v_0 = W$,

$$F = \frac{w\,v_1^2}{2g}\left(1 - \frac{v_0^2}{v_1^2}\right)a_0 = \frac{W}{2gv_0}(v_1^2 - v_0^2)$$

but, as is seen by referring to Fig. 5,

$$v_1^2 = v_0^2 + V^2 + 2Vv_0 \sin\beta_0$$

so that $F = \frac{W}{2gv_0}(V^2 + 2Vv_0 \sin\beta_0)$.

Now F is repeated twice in each complete circuit round the channel, once at the passage from the turbine pipe to the casing pipe, once vice versâ. So that for the complete Potential due to the circuit we may put $F' = \frac{W}{gv_0}(V^2 + 2\,Vv_0 \sin\beta_0)$ . . . (2)

These two equations (1) and (2) at once establish a coherence and consistency in the solution as follows. The whole "work" or energy employed in driving the turbine, must, as we have seen, go either into the acceleration of the streams before the steady flow is established, coupled with the work of friction due to the existing flow; or ultimately into work of friction simply: and in either case, the "work" done by the Potential upon acceleration and friction should equal the "work" done in driving the turbine, and the comparison is now easily made.

Calling the work per second in driving the turbine, U_Φ we have

$$U_\Phi = \Phi V = \frac{W}{g}(V^2 + 2Vv_0 \sin\beta_0)$$

Calling the work per second done by the Potential, U_F we have

$$U_F = F'v_0 = \frac{W}{g}(V^2 + 2Vv_0 \sin\beta_0)$$

The two values are, as they ought to be, identical.

But further, by assuming a coefficient of fluid friction, of the form, Friction $= f\,v^2$, we can establish the relation which will subsist between V and v_0 when the friction has become equal to the Potential.

In this case we shall have

$$f\,v_0^2 = F' = \frac{W}{g\,v_0}(V^2 + 2\,V\,v_0 \sin\beta_0),$$

the solution of which, observing that $W = wa_0v_0$, is

$$\frac{V}{v_0} = \sqrt{\frac{g\,f}{w\,a_0} + \sin^2\beta_0} - \sin\beta_0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

so that in any given pipe $\frac{V}{v_0}$ is constant.

From this it follows that, if each of the imaginary pipes had real sides by which the friction operated, we could define the speed of flow

at the various distances from the vortex centre. For suppose the girth of each pipe to be the same, say k; then its length would be as its distance (r) from the vortex centre, say $l = 2\,\pi\,r$, and we could substitute for $f v_0^2$, $f' \times 2\,\pi\,r\,k\,v_0^2$, f' being the coefficient of friction per unit area at unit speed.

This assumption would make

$$\frac{V}{v_0} = \sqrt{\frac{2\,f'\,\pi\,r\,k\,g}{w\,a_0} + \sin^2\beta_0} - \sin\,\beta_0$$

so that under these circumstances (the pipes being real pipes) the speed in each pipe would be an inverse function of its distance from the vortex centre. In point of fact the introduction of so much internal skin friction as the reality of the pipe skins would involve, would, on the whole, create great retardation; and since the exterior layers of each vortex are exposed to friction both on the circumference of the channel and against the diaphragms, whereas the friction of the interior streams is due to the diaphragms alone, it is probable that the ultimate arrangement of the internal speed will possess some analogy with that belonging to the true vortex, in which the speed of each stream line is inversely as its distance from the vortex centre.

Whatever law is assigned to the action of the friction, the equation for $\frac{V}{v_0}$ admits of being shaped accordingly; and by introducing the value thus determined, into equation (1) we could frame a differential equation for the total force-moment of the machine in terms of V. And the equation if not integrable by regular methods would in any given case admit of graphic integration. But as a step towards this completion of the theory, careful experiment is still needed.

Mr. Froude exhibited a working model of the dynamometer, and sectional models showing the internal construction. In explanation of what had been spoken of in the paper as the power of current-growth in the cells of the dynamometer, he gave the following illustration by means of the sketch shown in Fig. 8, Plate 40: supposing a jet of water were issuing from a nozzle A with a velocity of 10 ft. per sec., and that it were caught by a fixed bent tube B C of the same bore as the jet and bent to a semicircle; then the water would evidently enter the bent tube at B with a velocity of 10 ft. per sec., and be discharged at C with the same velocity, while in passing round the bend it would in virtue of centrifugal force exert a pressure tending to move the bend away from the jet. Now supposing the bent tube, instead of being fixed, were made to move in the direction shown by the arrow D at the rate of 1 ft. per sec., or in other words to approach the issuing jet A at that speed: then it was evident that the water, instead of entering the bend at 10 ft. per sec., would enter it at 11 ft. per sec. relatively to the bend, and would pass round the bend at this velocity, finally escaping at C with a velocity of 11 ft. per sec. relatively to the bend, but of 12 ft. per sec. relatively to any fixed point. Thus a forward motion of the bend at the rate of 1 ft. per sec. would result in accelerating the flow of water at C by 2 ft. per sec. If now the water issuing at C entered a fixed semicircular bend, it would traverse this bend at 12 ft. per sec., and on issuing from this fixed bend at 12 ft. per sec. might be further accelerated by being passed through a second moving bend; and so on *ad infinitum*, assuming that no frictional or other resistances existed. The moving bend in this illustration might be considered to represent one of the half-cells in the turbine or moving portion of the dynamometer; and owing to the oblique position of the dividing diaphragms, the half-cells in the rotating turbine might be considered to be constantly approaching those in the fixed casing, so that the water on its discharge from the casing cells into the turbine cells underwent an acceleration which became continually augmented until the frictional resistance encountered in traversing the cells was equal to the speed-producing power. The resistance to the rotation of the turbine consisted in the resultant, in the plane of rotation, of the centrifugal

force exerted by the current when traversing the curved contour of the cells in the turbine; this resistance was of course equal to the force exerted in the opposite direction upon the cells of the fixed casing.

Another illustration had been suggested by Mr. Bramwell in explanation of the action of current growth: supposing a locomotive carrying a perfectly elastic target in front of it were approaching a perfectly elastic wall, and that a perfectly elastic ball were set vibrating between the wall and the advancing target; then it was evident that each time the ball struck the advancing target it would rebound towards the wall with a velocity augmented by double the speed of the advancing target, and would be returned each time from the wall to receive a further augmentation, and so on until it would gain an infinite speed. In this case the ball represented the water in the dynamometer, the advancing target represented the rotating turbine, and the wall represented the stationary casing.

From a consideration of this mode of action in the generation of currents within the instrument it followed that the power-absorbing capability of a given dynamometer of this kind, driven at a given speed, would depend upon the velocity which the water currents could attain; and this velocity being limited only by the frictional resistances, the smaller these resistances could be made, the greater would be the velocity attainable; so that, if the frictional resistances to the movements of the water could be done away with altogether, the power-absorbing capability of the dynamometer might become infinite at any speed of rotation of the turbine. This pointed to the fact that the power-absorbing capability would depend to a considerable extent upon the smoothness of the internal surfaces of the dynamometer, with which the water came in contact; and this had been found to be the case in the instance of the larger of the pair of similar dynamometers mentioned in the paper, having turbines of 12 in. and 9·1 in. diameter. In the 12 in. instrument, which had originally afforded, at a given speed of rotation, a resistance represented by 100 lb., more diaphragms had subsequently been inserted for the purpose of experiment, and not proving satisfactory these were afterwards removed; and it was then found that, though the dynamometer was thus brought back to its original form, its

resistance at the same speed of rotation had fallen 28 per cent., or to 72 lb., which was attributed to the roughness of surface caused by pieces of solder left on after making the alterations of the diaphragms. To test this, the roughnesses were to a great extent removed by scraping, and the resistance was by this means gradually brought up to 96 lb., although the full original resistance of 100 lb. could not be regained.

With regard to the statement made in the paper that, for two strictly similar but differently dimensioned instruments, the respective "moments of reaction," with the same speed of rotation in each, would be as the fifth power of their respective dimensions, this conclusion was arrived at from the consideration that, in the instance of comparing two dynamometers, one double the diameter of the other, and both driven at the same number of revolutions per minute, the mean linear velocity in one case would be double that in the other, and the resistance would therefore be as the square from this cause alone. But in the larger instrument the area acted upon would be four times as great, that is, it would be as the square of the increase in dimensions; so that there would be four times the resistance acting on four times the area in the larger dynamometer, and the effective resistance would thus be in proportion to the fourth power of the increase in dimensions. In addition the resistance was opposed at a mean of double the radius; thus causing the final result to be that the power-absorbing capability of the dynamometer was in proportion to the fifth power of its linear dimensions.

The PRESIDENT was sure that not only would this very important invention and discovery of Mr. Froude's be of immense service in a great many cases where they were at present very much in the dark; but also by means of this apparatus they would certainly be able to obtain a great deal of information on hydraulic subjects. Beyond that, he thought the application of this apparatus might be extended to a number of other dynamometrical experiments and uses.

Mr. P. BROTHERHOOD suggested that the apparatus now described was capable of being arranged to form an admirable marine-engine governor.

Mr. W. E. Rich observed that the heating of the water contained within the dynamometer was the first important point that struck him in regard to this most ingenious instrument. He had roughly calculated that, if the whole quantity of water contained in the dynamometer were equivalent to a disc 10 ft. diameter and 1 ft. thick, then in absorbing 8000 H.P. from the screw shaft the temperature of the water would rise about 70° Fahr. in every minute, which would be a very important amount of heat. If cold water were allowed to come in from the outside and to flow through for the purpose of keeping down the temperature, it appeared to him that there would be some change in the conditions of the vortices within the dynamometer, though what the change would be he did not at present see; but he thought, if there were anything of a flow through the instrument, this would somewhat alter the circumstances of its action. Another point in regard to the heating of the water was that this would alter the conditions of its friction, because the friction of all fluids varied as their densities; so that in that way again the heating of the water would influence the resistance of the instrument. If it were possible to cool the water contained without changing it, it would be necessary to provide valves that would let water flow out as it gained in temperature, and also let in water as the temperature fell, otherwise the casing might burst or air spaces or vacuum spaces might occur inside it.

With regard to the crescent-shaped sliding shutters inside the dynamometer, for regulating its power-absorbing capability at any given speed, it occurred to him to suggest that it might be quite practicable to connect the adjusting gear, by which these slides were moved outwards or inwards, with the main lever from the dynamometer to the indicating apparatus, as was done in the friction-brake dynamometer, and thereby make the instrument govern itself; so that, if it were wanted to keep the dynamometer working at a uniform speed or a uniform power, the movement of the main lever should draw the shutters in or out, and so govern the resistance offered to the rotation of the turbine. The spring of the registering apparatus he noticed was a straight one, and from his own experience with dynamometers he much preferred that form of spring for such

purposes, for with helical and other springs it was difficult to get an accurate zero point to start from, while with straight springs it was generally easy to determine the zero with precision. The longer the straight spring was, the better, even though it might be necessary to increase the strength, as it was a great advantage to have plenty of range. The straight spring shown in the drawing appeared to be quite uniform in thickness throughout its entire length; but he thought it was better to have a uniform width of spring in plan, and to taper the thickness to a parabolic outline. The mode of supporting the spring on knife-edge bearings slung in links, so that it was subject to no sideways stress, and supporting the spring at the level of its neutral axis, was novel and no doubt most advantageous.

He enquired whether any experiments had been made with a single-sided turbine and casing, instead of the double arrangement shown in the drawings, to ascertain what was the amount of the positive or negative thrust in that case; he presumed the tendency would be for the turbine to be sucked towards the casing, and this would have to be provided for in some way if the one-sided arrangement were employed.

Mr. J. H. Wicksteed asked whether it would not be practicable to alter the power of the dynamometer by means of altering the quantity of water contained in it, instead of by contracting the water passages by means of the sliding shutters.

Mr. C. Hawksley suggested that the cooling of the water in the dynamometer might perhaps be effected by means of a supply pipe from the deck of the vessel to convey cold water down to the instrument, and an escape pipe to take the hot water away from it up to the deck, so that the two columns might balance one another. The cold water having a very low velocity on entering the dynamometer, would have to be put in rapid motion; and the effect of this would have to be considered in the results obtained from the dynamometer, for which purpose the quantity of cold water supplied to the instrument or of hot water discharged from it might be ascertained by measurement.

Mr. E. A. COWPER remarked, in reference to the suggestion just made, that it would not be necessary to have any pipes communicating with the dynamometer, but simply two holes judiciously placed, one towards the centre and one towards the circumference of the casing; the water would then go in at the one hole and out at the other. He did not consider it would be requisite to measure the quantity of water passing through; the whole of the power was used in churning up the water, therefore it must be converted into heat, and if the heat of every particle of water so heated were measured, it was true that an exact measure would be obtained of the power exerted; but that would be a very roundabout way of getting at the result, and many losses through conduction and radiation would have to be taken into account, so that it would not be easy to get at the exact result; if it could be done accurately, it would however be an exact measure of the power exerted. Roughly speaking, the dynamometer seemed to be a most ingenious apparatus for churning up the water, and absorbing as much power as possible in so doing. The moving paddles or diaphragms were apparently arranged in the most scientific form for causing the production of very quick-moving currents of water, and then the fixed paddles or diaphragms were well adapted for checking such currents, thus absorbing the greatest amount of power, and producing a pull or strain on the casing of the machine which could at once be measured. This dynamometer reminded him of some of the liquid governors for steam engines; in Siemens' governor the vertical cup rotating on its axis threw the water over its edge at the top, and drew in a fresh supply of water at the bottom; and advantage was taken of the resistance so produced to make the governor pull the throttle-valve over, and it acted very well indeed when everything was in good order. In another governor there was a simple paddle revolving in a case having fixed paddles; and the power absorbed in driving that increased considerably with the speed. The resistance of this dynamometer was very slight indeed at a slow speed; but on turning a little faster it increased very rapidly, and no doubt this dynamometer would make a very excellent governor.

With reference to the spring in the indicating apparatus, he agreed with Mr. Rich that the most scientific spring was a long flat spring, tapering in thickness as well as in width, so that the metal might be strained to the same extent throughout its entire length; a spring of that description had been made by Professor Moseley for his dynamometer many years ago, and had been found to answer well.

He thought Mr. Froude had designed an admirable instrument for the purpose of ascertaining the exact power that engines exerted at the end of the screw shaft. Many experiments had previously been made by Mr. Froude as to the resistance of ships through the water; but nothing was at present known as to the exact power exerted at the end of the screw shaft; possibly the results might be somewhat astonishing. It ought to be known what power was being delivered at the end of the screw shaft; and this knowledge would lead to improvements in the engines, probably to the construction of engines with the least possible amount of friction. The space in a small ship was very circumscribed for getting in a large amount of power, and led to the adoption of very short strokes. Perhaps the stroke would be lengthened somewhat, if it was found through the agency of this dynamometer, as he expected would be the case, that a great deal of power would thereby be saved, owing to reduction of friction and greater expansion. That was a point which greatly needed investigation; and he thought this instrument would give the means of arriving at the knowledge which was wanted.

Mr. W. Hartnell remarked that, in employing the dynamometer for determining the power of engines, it would be unadvisable to draw any conclusions from the results obtained from new engines, because the friction of a new engine was so greatly in excess of its friction after running for a short time that results so arrived at would necessarily be fallacious. After a small engine had been running several weeks the horse power exerted on a friction brake rose to as much as 90 per cent. of the Ind. H. P., but when quite new he had observed the proportion was frequently only 60 or 70 per cent., increasing rapidly. A new high-pressure engine often took 12 or 14 lb. per sq. in. pressure to keep it running unloaded on first trial.

Mr. A. PAGET, referring to Mr. Rich's suggestion that the amount of water allowed to pass through the dynamometer would materially affect the action of the vortices, asked whether it was not absolutely essential, for enabling a correct estimate to be made of the power used, that the quantity of water passed through the instrument should be accurately measured.

Mr. J. PLATT thought the same end might be attained by circulating the water through pipes connected to a refrigerator, so as to regulate the temperature to any degree, and keep the same quantity in the instrument.

The PRESIDENT considered this was a most valuable contribution to mechanical science; he did not think it possible at present to foresee what was to come out of it; it led to a great number of reflections upon hydraulic forces and hydraulic resistances. The principle of the machine—its most valuable principle—was that the force and the resistance were exactly balanced, and by reason of their being so exactly balanced they could be measured with great precision. There was as yet, he thought, a good deal to be made out by this instrument; and some discoveries would be made that would be very interesting, in regard to the dynamical theory of heat. He should like to know what would happen, supposing this machine continued a long time in action without any change of water; it appeared to him that the heat could not get out of it under such a state of circumstances; and he asked whether any experiments had been made upon this subject, and with what result.

Mr. FROUDE, in replying to the enquiries that had been made, observed that the point about the change of water in the dynamometer was an important one. It was no doubt essential that the water should be changed; and if the water were not changed, the first thing would be that it would speedily arrive at a boiling temperature, and then it would get hotter and form steam, and presently the instrument would burst. That would probably be the effect, for even when the dynamometer was working completely submerged under water the

rise of temperature would be rapid if the water inside the instrument was not changed; but he had not attempted to pursue the question further than the practical conclusions which were immediately in view: he saw that it opened up an endless vista of extremely curious questions, but he had not had the time to follow them all out. With reference to the effect on the machine of the change of water, no doubt it would be interesting to measure the exact quantity of water changed, and so on; but so long as that water had no circumferential velocity it was obvious that the dynamometrical condition was not altered. To throw away water that had velocity was to throw away work without measuring it; but the whole duty of this instrument was not merely to throw away work, but also with certainty to measure the force that was being exerted on the casing, or the work that was being thrown away. The whole essence of dynamometrical measurement consisted in the change from forward momentum to backward momentum. If all the circumferential momentum were taken out of the water that was discharged from the dynamometer, by making it pass through a straight radial jet, in that case all its dynamometrical duty would be taken out of it. This might perhaps not be apparent at the first glance; but it was certain that, if the water discharged from the casing of the instrument had no circumferential velocity, it must be producing no effect upon the dynamometer, and thus the power absorbed by the instrument would still be measured with the dynamometrical exactness required. If the casing were undergoing violent oscillations, the water coming out of a radial jet would have some circumferential motion, and so far there would be a defect in the measurement; but if the casing was regarded as stationary—and it was in fact approximately stationary—then the dynamometrical record was not vitiated at all.

With regard to the method of effecting the required interchange of water, the state of things inside the dynamometer was such that at the centre of the vortices there was a great depression of pressure; and he could fancy that by driving the turbine hard an actual vacuum would be created there. That at once afforded an opportunity for admitting any quantity of water, if the supply of cold water were led to the locality of the vacuum, by having little tubes running up

through the diaphragms of the casing and leading into the centre of the vortex, in this way merely leading the water where it was wanted to be supplied; and it would easily go out at any part of the circumference in consequence of the pressure existing there from the centrifugal force.

There was also another point which was important, namely, that the water when heated delivered up the air contained in it; so that, if the turbine were to go on for ever churning a fresh supply of water and making it hot, the result would be a great collection of air inside the dynamometer, which would alter the scale of force or the power-absorbing capacity of the instrument. It had been suggested that getting rid of a portion of the water might be a mode of adjusting the power-absorbing capacity; but though that plan would have the desired effect, it would not be so manageable a method as simply closing the apertures in the turbine by means of the sliding shutters, which could be done from the ship's deck or from the shore. It was easy to admit more water into the dynamometer, and if desired by putting on a little pressure the air might be expelled; that is to say, there might be two pipes leading through the diaphragms into the centre and the circumference of any given vortex, and by putting pressure on the water that was supplied through the former pipe, the air would be driven out through the other pipe. In the working model exhibited of the dynamometer there was a window in one side, and it was seen that, the moment the instrument was turned round, the air vanished from the circumference and went to the centre of the vortex. He had also constructed an apparatus to measure the speed of the water at each part of each vortex, and its pressure. The rise of temperature in the water in the dynamometer would no doubt exactly represent the power expended, if it were possible to count up all the heat, assuming the dynamic theory of heat to be, as he believed it was, indisputable and exactly quantified. On this basis he had calculated that with a dynamometer of the dimensions shown in the drawings, when absorbing 2000 H. P., a supply of 14 cub. ft. of water per min. would prevent the temperature inside the instrument from rising 100° above that of the incoming cool water, without allowing for surface refrigeration.

With reference to the automatic governing apparatus suggested by Mr. Rich, he doubted the prudence of it. There was this peculiarity in the dynamometer, that rapid alternations of speed did not immediately produce corresponding alternations of stress on the casing, because when a sudden change of velocity was produced in the turbine the reaction was not got up instantaneously to the full resistance corresponding to the change of speed, because the vortex speed had to be increased. This was clearly illustrated by an interesting experiment with the working model exhibited: in rotating it by hand and starting with a steady speed, it was found that the resistance did not come fully into play until a certain portion of a revolution had been passed through. And further, if a slight impulse was given to the handle, it would describe about half a revolution before being stopped by the resistance; and if the impulse was given with the utmost force that could be exerted, the handle could not be made to describe a greater arc before being stopped than in the previous case, on account of the resistance produced by the great amount of vortical motion that was set up. The well-known tendency to "hunt" in governors would be a good deal developed by attempting to render the dynamometer automatic in its action. The fact that there would be possible variations in the resistance experienced by the shaft driving the turbine was only what it would be subject to in its ordinary working; the only difference was that the variations in the dynamometer were incomparably smaller than those enormous variations of torsional force which the shaft underwent in passing the blades of the screw from the running water to the dead water, that is from the horizontal to the vertical position. Indeed, no one had yet succeeded in determining the strain thus produced on the screw shaft, or how much force was given out to the screw under those circumstances, half of the revolution of the screw shaft being always so hampered by the dead water that none of the results were worth having; in spite of all that had been done, including the use of enormous cataract cylinders, the jolt on the screw shaft was so great that any ordinary thrust-dynamometer diagrams were inferior, and could not be made much of.

The strength of the spring employed for the indicating apparatus was an interesting point; and of course, if it was a question of getting the utmost work out of a given weight of steel in the spring, he agreed with Mr. Rich that a spring tapering parabolically in vertical dimensions or thickness, and of uniform width in plan, would be the most effective, and would be as much as 50 per cent. more elastic than the spring shown in the drawing of uniform thickness and tapering in width. A parallel spring of uniform width and uniform thickness would bend to a cubic parabola; and if it were tapered as suggested to a parabolic outline in thickness, this would allow of a doubled deflection at the ends of the spring, and by that means a doubled amount of work would be got out of it. In the present case the object was rather to have such a form of spring for the dynamometer that there could be a certainty of getting the tempering uniformly done all through; and he understood from the best spring makers that with the form of spring shown in the drawing there was no difficulty in this. The uniform thickness would facilitate uniformity of elastication throughout the length of the spring. The spring at present employed was only a provisional design, and he expected to receive instructions from the Admiralty before long to prepare a working design for the whole instrument.

With regard to the remark that had been made about the reaction being obtained by churning up the water, that was true in a sense; but it was not the way in which he liked to represent the action of the dynamometer, because, as he had already explained, the less friction there was in the water, the more effective was the reaction. The object was as much as possible to direct the water exactly into an easy flowing curve, so that there should be as little eddying round the edges of the diaphragms as possible. That was essentially contrary to the notion of what might be called churning or tearing the water to pieces; whereas the smooth flowing of the vortex currents along the pipes or cells of the turbine and casing, only impeded by surface friction, was an easier motion, and one that allowed a greater total velocity to be kept up. With a view to that, he had no doubt it would turn out in fact, as it already turned out on investigation, that the edges of the diaphragms in each case should be a little canted

forwards, the diaphragms being bent at the edges to meet the incoming stream. Supposing that in an obtuse-angled triangle the two sides A B and A C containing the obtuse angle A were drawn parallel respectively to the divisional line between the turbine and casing and to the slanting position of one of the diaphragms; then making the length of the side A B proportional to the circumferential speed of the turbine, and the length of the side A C proportional to the linear flow of the water along the side of the diaphragm, it was clear that the compound speed was the diagonal C B, and a particle of water flowing along the side of the diaphragm was, in space, running not in the direction C A, but in the direction of the diagonal C B. If therefore at each point the edge of the diaphragm was slanted so as to receive the incoming stream, the direction of which bore a constant ratio to the circumferential speed of the turbine, a better effect would be secured: there would be less tearing to pieces of the water in violent eddies round the edges. That was a minor matter; but if it was wished to make a machine having the greatest power in the smallest compass, no doubt a gain would result from canting the edges of the diaphragms forward in the manner described.

With regard to Siemens' interesting governor which had been referred to, having a parabolic cup armed with ribs on the outside, so that all the water that ran up the inside and overflowed was obliged to take the circumferential motion of the cup, that governor was certainly isochronous, but it had its disadvantages as well as its merits. There was a great tendency to "hunt," in consequence of the reaction not occurring instantaneously. The governor ought if possible to anticipate any change in the force of the engine, not to follow it; if it was first left a little behind, and then got an excess of force, it would be constantly "hunting" or oscillating about a mean position. It was true that the alternations of velocity were confined within a short compass, so that with long lines of shafting and extensive machinery intervening, as in cotton mills, no great harm would result. But in dealing with delicate dynamometrical measurements, depending upon masses put in motion close to the engine, the fact of that hunting was a difficulty to be got over, and it became great in proportion as the governor approached strict isochronism, and it

became necessary to allow a little error in the absolute speed, in order to get rid of the large alternations of speed that occurred with an isochronous governor struggling to maintain its true course.

The friction of the engines was no doubt a very important question, and it was with a view to determining it that this dynamometer had been devised; the greater amount of friction in an engine when new than after wear would be clearly brought out by its use. Allusion had been made to the possible gains which it might be hoped to derive from the employment of such an instrument, and he had no doubt that many would be glad to get the benefit which it would give. Several marine-engine builders had regarded it with great interest, being convinced that they really did not know how any engine would work, and that they had at present no means of ascertaining this. That the friction was extremely great in large engines an interesting proof was furnished in some trials carried out by Mr. Denny of Dumbarton, who had not contented himself with trying ships at full speed and half speed, but had run them at a great variety of speeds, arranging the results in the form of a diagram of the horse power. Taking the abscissæ along a horizontal base line to represent the speed, and the vertical ordinates to represent the horse power due to that speed, a curve was obtained convex towards the base line and commencing at the zero point of speed. It appeared preferable to himself however to transform this curve of horse power into one of simple pressure, in order to arrive at a determination of the engine friction, because the speed factor of the horse power curve was one which reduced that curve to a zero result at zero speed, inasmuch as if there were no speed there would be no horse power, however great the pressure, and on attempting to deduce the engine friction from the horse power the result would be no friction at all of the engine when running empty. The horse-power curve when transformed into one of pressure, working backwards from the highest horse power developed, produced a somewhat different curve, dropping less rapidly towards the base line in proceeding backwards, and therefore not running down to the zero point at all, but to a point which would not by any distortion come to zero, giving thus a definite ordinate at the zero point of speed. This ordinate represented in tons, or in lbs. per sq. in.,

according to the vertical scale employed, the constant friction of the engine, that is to say the dead-weight friction or the mere force employed in pushing the piston along the cylinder when doing no work; and as the friction was independent of the speed to a certain extent, it might be assumed that the same amount of friction existed throughout the range of speed tried. The actual amount of the friction had been thus deduced from many experiments, which gave approximate results of the same kind, and it had been found that this ordinate of minimum pressure, representing the engine friction, was about 1-7th of that of the maximum pressure; so that an engine which required at its maximum working power to have say 21 lb. per sq. in. on the piston, must have, to keep it going at all without doing extraneous work, a pressure of 3 lb. per sq. in. or thereabouts. That result had come out with considerable consistency; yet, though the general tendency of the experiments was to show a large constant friction, that constant friction was different in different engines. The difference could not be ascertained with exactness at present, but the dynamometer would give the means of getting at it. With the aid of the dynamometer it would be possible to work an engine at any pressure throughout any variations of speed in the trials made: it could be run with a high steam pressure either at a high speed or at a low speed, and also with a low steam pressure at a high speed or a low speed; and thus results would be obtained as to the working of engines which they had hitherto been in the dark about.

The President remarked that the dynamometer now described would give the means of determining what had been denominated by Prof. Moseley "prejudicial resistances" of all kinds. He moved a hearty vote of thanks to Mr. Froude for this very important communication; and hoped that at some subsequent meeting he would be so good as to complete his communication by adding the results of the further experiments and investigations upon which he was now engaged.

The vote of thanks was passed.

The following paper was then read :—

ON THE ECONOMY OF VARIABLE AUTOMATIC EXPANSION IN STEAM ENGINES.

BY MR. JOHN C. FELL, OF LONDON.

The economical use of steam is a subject that receives much attention, and the further reductions which are being constantly effected in fuel consumption show that there is still room for improvement in that direction.

For the use of steam in the most efficient and economical manner a considerable degree of expansion is required; and the theoretical gain by different degrees of expansion ranges from 13 per cent. when cutting off at 7-8ths of the stroke to 208 per cent. when cutting off at 1-8th. The amounts for intermediate degrees are shown in the following table, in which the initial steam is taken in each case at 60 lb. per sq. in. total pressure including the condenser vacuum, and the mean pressure p in the cylinder is calculated by the ordinary formula $p = \frac{P}{R}(1 + \text{hyp. log. } R)$, in which P is the initial pressure and R the ratio of expansion.

Fractional Cut-off.	Ratio of Expansion, or of Distances travelled by Piston under expansion of 1 vol. of steam.	Mean Total Pressure. Lb. per sq. in.	Comparative Work done by 1 vol. of steam.	Percentage of Relative Gain.
1	1·00	60·0	60·0	0
7-8	1·14	59·5	67·8	13
3-4	1·33	57·8	77·1	28
5-8	1·60	55·1	88·2	47
1-2	2·00	50·8	101·6	69
3-8	2·66	44·6	118·9	98
1-4	4·00	35·8	143·2	139
1-8	8·00	23·1	184·8	208

These theoretical comparisons of relative economy are however found to be considerably reduced in practice from the fact that the

surface, cooling the steam by radiation, is increasing in the same ratio as the distance travelled over, or as the ratio of expansion. Thus when expanding eight times, the total surface over which the same weight of steam passes is eight times greater than when working with no expansion at all. This will then in the former case multiply the percentage of loss from outside radiation eight times compared with the latter case. A further loss is also occasioned under high grades of expansion by the liquefaction of the steam due to the performance of expansive work.

Consequent upon the general acceptation of the very considerable economy resulting from the use of steam at high rates of expansion, much attention has been directed to the designing of engines for using steam at exceptionally high rates of expansion. This source of economy has probably been sometimes pushed beyond its practical limits of efficiency. When the initial pressure of the steam is but moderate, such as from 40 to 60 lb. per sq. in. above atmosphere, the practical limit of economical expansion for average work is soon reached at a cut-off of about 1-4th to 1-6th. This is occasioned by two principal facts: first, that for higher grades than this the theoretical increase of efficiency gained from the steam proceeds but slowly, while at the same time the practical causes of loss from radiation and condensation are increasing at almost or quite an equal rate. Secondly: there will be always a practical limit to economical expansion, depending upon the ratio of the dead load on the engine to the initial pressure at which it is working. This will be seen from the consideration that the work of an engine is twofold, namely the overcoming of dead resistance of plant and shafting, and also the effecting of a balance of useful work beyond this. When the engine is capable of overcoming the dead resistance only, with no balance for effective work, it may as well be stopped at once, for any steam then expended is literally thrown away, as it effects no margin of useful work. In such a case theoretically the motor would stop as soon as equilibrium was established by reduction of pressure; but in practice the momentum of the flywheel carries on the engine over this non-effective point, and it would not be noticeable but from inspection of the indicator diagrams. The result of this action of the fly-

wheel is that, when the motive power of the engine falls below the dead resistance, any useful work or any portion of the dead resistance overcome is effected by work borrowed from the early portion of the stroke and stored up in the flywheel.

This is no loss of work or economy until a portion of the dead resistance is overcome by the momentum of the flywheel; after that point the flywheel is robbing the effective work of the first part of the stroke in order to overcome the dead resistance of the latter part of the stroke, thus causing a distinct loss in the economical working of the engine. The limit of economy in expansive working can be thus fixed—that the steam shall not be allowed to fall in average working below that pressure which is sufficient to overcome the dead inertia and frictional resistances of the engine and plant. Though this may be taken as a rule in fixing the best rate of expansion for average working, it does not necessarily mean that the engine should not have the capability of cutting off the supply of steam at any desired and earlier portion of the stroke, should the work become much reduced; for it will now be shown that this method is greatly preferable to and more economical than that of throttling down the steam to a reduced pressure.

The economy which may be thus effected by always using the steam at full boiler pressure, with the maximum expansion that the work will admit of, may be at once ascertained by an inspection of indicator diagrams. Those shown in Figs. 6 and 7, Plate 46, are a series taken from a large rolling-mill engine, subjected to considerable variation of load; they were taken at considerable intervals, so as fairly to represent the variations in the work of the engine throughout the day. The engine is one of a pair, with cylinder 42 in. diam. and 6 ft. stroke, and was in first-rate order, and considered to be working at a very fair rate of economy.

The simplest method of ascertaining at what improved economy the engine might have worked, under conditions of variable automatic expansion, is to estimate what might have been the maximum work which could be obtained from the steam when used at the fullest rates of expansion. This estimate may be most easily made by constructing theoretical expansion diagrams, which shall represent

exactly the same amount of steam finally delivered to the condenser as in the case of the actual diagrams under notice. The calculations by which this may be done are founded on the two simple facts that in each of the throttled diagrams the final pressure at the end of the stroke is the pressure at which one cylinder full of steam is discharged into the condenser, and hence represents the actual weight of steam used per stroke; and also that the initial pressure is known, namely 33 lb., at which that steam might have been admitted into the cylinder from the boiler. It is then a matter of simple calculation to decide the ratio of expansion or the point of cut-off, which with this initial pressure would produce the given final pressure at the end of the stroke. In this way for each throttled diagram a theoretical expansion curve is constructed, as shown by the fine dotted lines in Figs. 6 and 7, on the basis that the same final weight of steam is discharged from the cylinder in each of the cases that are compared. If now the actual work represented by the comparative diagrams be estimated—throttled versus expansive diagram—a just conclusion will be arrived at as to the relative economy of the two systems. These calculations have been made for the comparative diagrams shown in Figs. 6 and 7, and the following are the results obtained:—

	Throttled Diagram.	Expansive Diagram.
A	319 Ind. H. P.	319 Ind. H. P.
B	318 " "	349 " "
C	156 " "	270 " "
D	122 " "	246 " "
E	103 " "	211 " "
Totals,	1018 " "	1395 " "

From this comparison it will be seen that the advantage of true expansion versus throttling increases as the grade of expansion, and can in some instances reach as much as 100 per cent. economical advantage. However, taking the five original diagrams in Figs. 6 and 7 as averaging a day's work, the above comparison shows an advantage of 27 per cent. more work that might have been obtained from the steam actually used, if truly expanded at all times to suit the varying load. The practical result would be, not that so much more

work would have been obtained from the steam actually used, but that proportionately less steam would have been required to effect the work actually performed.

This variable expansion must, to be of practical use, be effected by a governor adapting itself automatically to the particular work required in any revolution, without attention from the driver. Rider's Variable Automatic Expansion Gear, which has been carried out and applied by Messrs. Hayward Tyler and Co., has been watched by the writer for some years, and its working and economical effects have been found to give great satisfaction.

This valve gear, which is shown in Figs. 1 to 5, Plates 44 and 45, is of the simplest character, and varies as little as possible from the ordinary under and upper cut-off slides, worked by two eccentrics set at right angles to each other. The main valve D, Figs. 3 to 5, is the ordinary D slide-valve, except that the seat for the upper or expansion valve C is circular, struck radially from the centre of the expansion-valve spindle; and the upper faces of the steam passages are brought through the main valve not parallel, but inclined to each other at an angle of about 45°, which is done by twisting the cores. The expansion valve C differs only from the usual upper valve in that it is cylindrical, and has its two outside edges inclined to each other so as to contain an angle of about 90°, and so as to form a nearly right-angled triangle twisted into a cylinder. This peculiarity of construction in the cut-off valve and in the ports through the main valve is adopted so that the cut-off valve C can rotate on its own valve spindle, and by such rotation bring a relatively narrower or broader part of the triangular valve between the steam admission ports.

As the stroke of the expansion valve from its eccentric remains the same and unaffected by the rotation round the valve spindle, the timing of the cut-off varies with the angle of rotation round the spindle from maximum to minimum. The maximum range of cut-off may be to final closing altogether, and the minimum range of cut-off to admitting steam without cut-off for full stroke, except only partial cut-off by the lap and lead of the lower valve. This lap on both steam and exhaust side of the lower valve with suitable lead should

be retained, in order to give a suitable cushioning by the steam and easy working over the dead centres.

The rotation of the expansion valve round its own spindle is readily effected by suitable governors of the pendulum dead-weight type, which to be most thoroughly effective should not be too high in the balls. The vertical rise and fall of the balls is communicated to a sleeve A, Fig. 1, which raises or lowers a toothed rack. The toothed rack gears into a toothed quadrant B on the expansion-valve spindle, as shown by dotted lines in Fig. 5; and the rotation of the valve C is thus secured by the rise and fall of the governor balls.

There is nothing in this gear to get out of order or to wear rapidly, and some five or six years' working in this country has now shown it to be thoroughly trustworthy and economical. It is difficult to obtain definite data in figures as to the economy effected in practice amongst steam users by any such mechanical improvement as the valve gear just described; but within the last few weeks the writer has been able to gather the following practical results, which amply serve to confirm the theoretical deductions previously made in this paper.

This variable automatic expansion valve gear has been applied with new cylinder 14 in. diam. by 30 in. stroke to a compound engine, with high-pressure cylinder as above, and low-pressure about 21 in. diam., the expansion gear being fitted to the high-pressure cylinder. Previously this engine was worked with an ordinary throttle-valve governor at a consumption of about 20 cwt. per week. The consumption is now reported by the owners to be reduced to 16 or 17 cwt. per week, which shows an improvement in economy of from 15 to 20 per cent. This engine is supplementary to water power, and is thus only working through part of the week and at low power.

This gear was also applied to a new 60 H. P. compound condensing engine sent out to India, of which the reports are that it is the most economical engine in the neighbourhood (Calcutta); but no definite data are to hand.

A 12 H. P. non-condensing engine, fitted with this gear, was put down to replace a condensing beam engine, rather old; and the

owners now report a saving of 2 tons of coal weekly. This is partly owing no doubt to the tightness of the piston and to the general efficiency of the new engine, and not to the valve gear alone.

A similar 12 H. P. non-condensing engine, fitted with this gear, was put down with Cornish boiler to replace a 12 H. P. portable engine and boiler; and the owners report a saving effected by the new engine of 18 cwt. of coal per week, and are obtaining about 33 per cent. more work from the engine. They have also saved a further 18 cwt. of coal per week by substituting bark and rubbish for that further amount of coal.

These, with other general favourable reports, fully serve in the writer's opinion to show the practical value of this good system of variable automatic expansion. The promptness and efficiency of regulation by this valve gear are most marked. The work on the engine when working up to full power may be suddenly thrown off altogether with perfect safety, and if the valve is set correctly the engine will hardly increase its velocity appreciably between maximum work at $\frac{3}{4}$ cut-off and running empty. The following experiment has been reported to the writer by the manager who conducted it: an engine employed to drive fulling mills in the neighbourhood of Bristol had been fitted with this valve gear, and when the valve gear had been properly set and fixed, a crucial test was made upon the steadiness of the engine; both mills were thrown off together, and the speed of the engine was not perceptibly increased, to the observation of those standing in the engine house.

Mr. Fell exhibited a working model of the variable automatic expansion gear described in the paper, showing its action for various grades of expansion.

Mr. W. Froude remarked—in reference to the limit of economy of power, mentioned in the paper as fixed by never reducing the pressure of the steam below that which was necessary to overcome the dead-weight friction of the engine—that he did not think that was the true limit; because if there was a certain amount of work to be done in the stroke, this involved necessarily the travel of the piston and the whole of the machinery through its entire length of stroke. The work had to be done somehow; and the question was what mode of using the steam would do that work most economically. Steam wire-drawn down to a moderate pressure and acting through the whole stroke would involve a greater expenditure of heat and steam than admitting a little steam at the highest pressure at the beginning of the stroke, and letting that give the flywheel a push, and then expanding it down through the remainder of the stroke. Supposing the engine were not working with a vacuum at all, and that steam enough were admitted to carry the piston with constant pressure through the whole stroke, then if the steam finally filling the cylinder at that pressure were compressed up into the space it would have occupied at the beginning of the stroke if admitted at boiler pressure, that would show how large was the volume of steam at boiler pressure required according to the principle involved in the paper for producing a final pressure not below what was capable of moving the piston; but the benefit of the potential expansion of the steam would be lost in that case. For driving a large engine when only a small amount of work was wanted out of it, nothing better could be done than to let steam in at the highest pressure, so long as this did not occasion an undue jumping strain on the machinery. As far as economy of steam was concerned, he thought the value of expansion was not strictly limited by making the cut-off such as never to reduce the pressure below that which would move the machinery at the time; if there had been work enough done by the steam in the earlier part of the stroke, the accumulated inertia would enable the expanded steam to carry the machinery through the latter part of the stroke. He did not wish it to be supposed that he advocated indiscriminately a high cut-off; he merely considered that the particular limit specified in the paper—

ceasing to cut off when the expansion would bring the final pressure down so low as to equal the dead load of the engine—was not the critical limit that ought to be employed, and there was another practical limit.

Mr. W. HARTNELL said, in reference to the point which had been raised as to how far expansion could be carried in a single cylinder, he quite agreed with the author of the paper that the extent was much less than was generally supposed. Although the final pressure should be sufficient to overcome the resistance of the dead load, including both the shafting and the engine, yet from that point of view the expansion might often be carried a little further by increasing the speed of the engine relatively to the shafting; for then part of the dead load relatively ran slower, and less pressure on the piston would balance it. The peculiar requirements in the engine trials of the Royal Agricultural Society, in which the engines were required to run as long as possible with a given weight of coal proportioned to the dynamometrical horse power, gave rise to practical investigations by means of the friction dynamometer to discover the most advantageous limit of expansion in regard to the useful horse power, excluding the dead load; and many unpublished experiments had been made with various degrees of cut-off to find how little water could be used, or how long the engine could run. The most effective results were at the Cardiff engine trials in 1872; if these were looked into he believed it would be found that most of them led to the conclusion that with 80 lb. initial steam pressure above the atmosphere the most desirable cut-off was that which balanced about 36 lb. per sq. in. mean piston resistance. But that was not the practical problem which had to be met in driving a mill. Any one who had to put down an expensive engine would want to obtain a certain economical value; and in the last part of the stroke the power must not be just equal to the resistance, but must be so much greater as to pay for the cost of putting the engine down. Some engineers had been carried away by the expansion theory, and had started at high pressure with early cut-off, but had only succeeded in saddling themselves with expensive engines doing a small amount

of work; whereas by cutting off later in the stroke the same amount of effective power would be obtained with a smaller engine at less total daily cost, which was what had to be arrived at, for an engine was merely a machine to produce an economical effect.

As to the economy of fuel with a variable cut-off, it was difficult to say what amount of economy was realised in actual practice; but as far as he had observed in high-pressure engines it was even greater than the 15 to 20 per cent. mentioned in the paper as obtained with the compound engine referred to; if an ordinary high-pressure engine with a variable load had been taken, the economy would have been much higher. He had never succeeded in getting more than rough data, but he had noticed apparently as much as 1-3rd, which was a very high saving. There was an idea amongst users of high-pressure engines, which he feared was countenanced even by engineers of standing, that the larger the cylinder employed for doing certain work the cheaper the work would be done. If it were generally known that the variable automatic cut-off gear often saved from 25 to 33 per cent., but few more high-pressure engines without such gear would be employed, except for temporary purposes.

Another point mentioned had often been brought forward, in connection with the Corliss valve-gear especially, that with the automatic cut-off the whole load might be suddenly thrown off the engine, and the result would be only a small increase of speed. In engines with fixed cut-off gear he thought the cut-off was usually much too early, and that 1-4th stroke—certainly not 1-5th—was as early as was desirable for the cut-off. He remembered the case of some engines made by an eminent firm, having a 3 ft. stroke and cutting off at 1-6th to 1-8th, which had ultimately to be taken out because they would not do so well as compound engines working with a less total expansion: that is, they did not bring down the consumption of coal to so low an amount per net H. P. estimated by the weight of material ground in the mill. In another case two fine pumping engines erected for a large waterworks had the cut-off so early, that not only was the outlay excessive in proportion to the effective work done, but the water used per Ind. H. P. amounted to as much as about 30 lb. per hour, as estimated from the indicator diagrams.

Mr. G. B. OUGHTERSON said that in his own experience with compound engines and with automatic cut-off gear he had found that where an engine had to work against a constant load there was no practical economy in putting on an automatic cut-off. However in the instance of two engines with which he had made experiments, one of them, indicating about 150 H. P. having no automatic expansion gear, had a consumption of $15\frac{1}{4}$ lb. of water per Ind. H. P. per hour; the other engine was working a cotton mill, and was fitted with variable automatic gear, and it only consumed $14\frac{1}{2}$ lb.; he did not believe there were in this country many engines working with such economical results as those. His own opinion as to the automatic cut-off was, that in such establishments as cotton mills the great advantage of it was, that it gave perfect command over regularity of work, and an economical consumption of steam whatever load was upon the engine; but as to supplying it to all classes of engines, he could not say that his experience, however short, was in favour of that.

Mr. T. POWELL mentioned that, from several years' experience of expansive working, the conclusion he had come to in Woolf engines which he had constructed was that when an ordinary slide-valve was set to cut off at 60 per cent. in the small cylinder the automatic gear gave no additional economy, or not more than 4 or 5 per cent., with a constant load sufficient to keep the throttle-valve full open during the time of admission. If the engine was working under a variable load and passing from a heavy load to a small one continually during the day's work, then of course with the ordinary slide-valve there was a loss in wire-drawing by the throttle-valve, and the automatic gear would be of use; but if that were not the case the automatic gear would not be of use. In a cotton mill, or for any purposes where the load was varying continually, the automatic gear would be productive of economy; but where this condition did not exist he did not believe the automatic gear gave the benefit that was supposed; though it might be advantageous in case of accident, that did not concern economy of fuel, the only point under discussion.

Mr. W. E. Rich observed that there were many types of automatic expansion gear, and apart from the general question of the advantage of such gear he did not see any special advantage in the particular construction described in the paper; on the contrary he thought there were some great objections to it. The cylindrical expansion slide-valve shown in the drawings was a form that he feared would speedily leak; and he should think that the loss by leakage of steam through it would more than compensate for the gain by the automatic expansion. Moreover the force required to rotate that valve in working would be considerable, and a very powerful governor must be employed for the purpose, otherwise the valve would be liable to stick when a gland was tightened, or if dirt came over in priming. There would also, he should think, be a great tendency in the rotating valve to hang back when a port was covered and the extreme steam pressure was consequently upon the valve; the governor would then jerk the valve in turning it round, as soon as the steam pressure upon it was relieved by the opening of the port, and this would produce a jerky and perhaps a hunting motion. All things considered, he thought this cylindrical valve would require much more governor power to work it than a flat cut-off slide; it had many disadvantages, and no greater advantages than were possessed by the common Meyer's double-plate expansion valve with right-and-left-hand adjusting screws, worked by a governor, as applied by Messrs. Clayton and Shuttleworth in their portable engine tried at Cardiff in 1872. One point with regard to the Meyer expansion gear, and all those which kept the eccentric in a constant position, was that they cut off efficiently between very moderate limits only; those limits were suitable for a compound engine, but for a single-cylinder engine, if it was wanted to go to high degrees of expansion, the steam could not be admitted far in the stroke, say not beyond 1-4th, whereas unless at first it were admitted for about 5-8ths of the stroke there would be a difficulty in starting the engine. As a general principle, in order to get a thoroughly good automatic expansion gear, working with ordinary slide-valves, he thought a movable eccentric must be employed, so as to admit of a good range of expansion from a small to a great cut-off. For pumping and other engines working under

uniform loads, or only varying once or twice a day, automatic expansion gear he thought was altogether unnecessary; it was a great complication, and practically there were few enginemen who would be at the trouble of keeping it in order, or keeping it at work. For uniform work it was better to have either a movable eccentric, or a right-and-left-hand screw, as in Meyer's valve, for adjusting the expansion by hand. For very variable work, not only must the variation of the work be considered, but also the class of hands in which the gear would be placed, because with complications of that nature it was difficult to get enginemen to take the trouble to look after them. At the Cardiff trials in 1872 he had assisted in testing the several portable engines exhibited, and there were four or five all fitted with automatic expansion gear; Mr. Hartnell's valve he thought was the only one in which the eccentric was shifted, and that did as well as a single slide-valve engine could do. It would be interesting to know, but difficult to ascertain, how many duplicates of these several types of automatic expansion portable engines had been made by the competing firms since; he believed they had made very few, and he doubted whether any of them who employed Meyer's valve gear had repeated it more than half a dozen times.

Mr. W. HARTNELL said he had found the Meyer expansion gear on high-pressure engines was liable to stick and thereby become useless; and those in charge of it would gladly get rid of it, because they would not take the trouble to shift the expansion valve by hand when required. If an expansion valve were set to cut off early in ordinary working, then under the heaviest load, when too much work was put on, the engine would simply stop, and if there was no one in the engine-house at the time to alter the adjustment of the valve, the engine would remain at a dead stop, and the whole factory too. This consideration required that an expansion valve if not automatic should be set to meet the heaviest load which could come upon the engine. Thus in order to be really of service a variable expansion gear ought to be also automatic, at least on a high-pressure engine subject to fluctuations of load. There was no difficulty in getting the entire range of cut-off from zero

to 5-8ths of the stroke by several simple methods; and he believed the gear shown in the drawings worked as well when cutting off at about 1-4th of the stroke as when cutting off later. He had concluded from experiments with small high-pressure engines, using the friction brake and indicator, that the only objection to the common slide-valve for expanding steam was that with early cut-off the piston had sometimes to be dragged by the flywheel near the end of the stroke, when the increasing compression on the exhaust side finally much exceeded the terminal steam pressure; at such times much useless friction was caused on the crank-shaft bearings. He preferred a separate valve for large engines, such as used for driving saw mills, &c. In running an engine with a very light load on the friction brake, the Ind. H. P. was perceptibly greater when the steam was cut off very early by expansion gear than when the pressure was reduced by throttling for the same load with a late cut-off. As to how often the engines fitted with automatic variable expansion gear had been repeated since the Cardiff trials, the makers of the engine that had been exhibited with his own gear had never used any other valve gear for engines of the same size which they had constructed since; and he was informed that although trade was slack at the present time they had not been able to make the engines with that gear as fast as they were required; the engine so fitted was more expensive than ordinary engines, and it was highly appreciated. Another maker had taken up a different way of effecting the variable expansion, and was beginning to make his engines freely with it; so that, without saying anything in favour of one construction of automatic variable expansion gear rather than another, he thought the principle might be regarded as a success, and that all who were taking up the subject were doing the country great service.

Mr. E. A. Cowper said that in order to represent the economy derivable from different degrees of expansion he had shown at a previous meeting a theoretical diagram of the true expansion curve (Plate 47), which had been drawn by himself and published by his brother; it showed the expansion curve from 120 lb. down to 2 lb. per sq. in. above a perfect vacuum. The indicator diagrams

accompanying the present paper showed, he considered, an engine that had too small cylinders, and was not made to work economically, not being large enough to allow of sufficient expansion; if the engine was required to exert as much power as the diagrams showed, it would have been much better to have had a larger cylinder and to carry the expansion out properly. He had himself expanded as far as 15 times in a compound engine, and had succeeded in reducing the consumption of coal as low as 1·3 lb. per Ind. H. P. per hour (though he did not recommend such great economy in all cases). In the indicator figures exhibited, the difference in economy between the full power diagrams and those showing a fair expansion must not be attributed, he considered, to the automatic expansion gear, but to the fact of having expansion. Very many engines had now the right-and-left-hand screw gear that had been referred to for regulating the degree of expansion; and the economy that had been got by that means, especially in the show trials of the Royal Agricultural Society, had been very great indeed. He agreed that the range of cut-off in an ordinary engine ought to extend from 1-10th to 5-8ths of the stroke; but it was not necessary for this purpose to move the eccentric round, in order to alter the lead. Both the lead and the stroke could be altered at the same time, without altering the eccentric at all, by employing a stationary expansion link vibrating on a fixed centre at one end and having the valve-rod attached to the free end, whilst the eccentric-rod was connected to the block working in the slot of the link, which was a circular arc described from the centre of the crank-shaft; the eccentric-rod being made very short, by shifting the position of its end in the link the stroke of the valve was altered by altering the leverage, and at the same time the lead was altered by altering the angle at which the motion was taken off from the eccentric. By that means the cut-off could be varied from 1-10th to 3-4ths, without any necessity for moving the eccentric.

With regard to the statement in the paper that a loss was occasioned under high grades of expansion by the liquefaction of the steam due to the performance of expansive work, it must be borne in mind that the conversion of heat into power could not be avoided, and the steam in expanding and giving out its power might become thereby so far

cooled that some of it was condensed into water. If steam-jackets were used thoroughly (and without them there was always great loss), that condensation might be prevented, and at the expense of so much more heat the steam would work so much longer; but it was impossible to avoid the loss of heat when it was converted into power. That ought to be regarded as the use of steam, and not the waste of steam.

A curved valve somewhat similar to the one shown in the drawings had been used by certain marine engine builders in London; but had been given up, on account of its taking too much power to move it.

Mr. A. Paget agreed in the opinion expressed by Mr. Rich, that if this engine were put into ordinary hands the loss by leakage of the cylindrical cut-off valve would, where the load was not extremely variable, soon be more than the gain by automatic motion. He enquired what portion of the circle was taken up by the port; and also what time it had been found that this valve would work in ordinary rough use before there was a serious detrimental leakage through it. A flat slide-valve, if it wore equally, kept itself tight; whereas the cylindrical valve must speedily begin to leak.

Mr. P. Braham thought the true value of fuel depended entirely upon the mode in which it was used by the stoker who attended to the engine in regular working; and a proposal had been made by Mr. Bramwell, he believed, that every engine exerting a very large power should have an automatic recorder, and that prizes should be given to engine-drivers who obtained the largest amount of power with the least consumption of fuel. The automatic recording instruments he believed were easily made, and not very expensive; and the emulation which such a plan would excite among engine-drivers themselves would be of great advantage to those who employed engines, and to the country at large.

Mr. T. Morgans considered the indicator diagram exhibited, showing the full work of the engine, was of the worst kind, proving that the exhaust had been seriously throttled in the return stroke.

If the full-stroke diagram were to be inverted, so as to get the steam admission line to be the exhaust line, and vice versâ, it would then become a tolerable diagram; and that would show, he thought, that the cylinder was really large enough for its full work, even when there was the greatest resistance upon it, and that a very good result in expansion might have been obtained with the maximum work in a cylinder of that size.

Mr. FELL remarked, with regard to the limit for economical expansion, that the limit assigned in the paper was intended to apply only to a fixed rate of expansion for average working; and it had been pointed out that this was not meant to imply that an engine should not be able to cut off earlier whenever the load became less than the average load. When the actual pressure of the steam in the cylinder had fallen below the average pressure required to overcome the dead load, the fly-wheel was practically doing dead work with no margin of effective power, and this dead work was therefore robbing the portion of the indicator diagram which represented the balance of effective power; that is to say, in any indicator diagram a parallel line might be supposed to be drawn at a certain distance above the bottom or exhaust line of the diagram, cutting away a portion from the bottom all along, which would represent a certain proportion of the work required to overcome the dead load, all above that line being the net balance of effective work. If the latter portion of the expansion line were allowed to fall below that parallel line representing the average work required to overcome the dead load, then, wherever it fell below that line, work must be supplied from the earlier portion of the diagram, which was the net balance of work. Therefore there would be an absolute loss in the latter portion of the stroke by robbing good work from the earlier portion; thus in a stroke of 24 in. the value of the last 4 in. might be altogether lost by the effective pressure in average work falling below the average resistance; in that case the last 4 in. stroke might just as well have been saved by shortening the length of the cylinder. For a fixed limit of average work therefore he advocated that the final steam pressure in expanding should be calculated not to fall below that required in average work

to overcome the dead resistance; and this view had been confirmed by Mr. Hartnell from the results of the experiments referred to as having been carried out at Cardiff.

With regard to the form of the full-power indicator diagrams exhibited (Fig. 6, Plate 46), those diagrams had been furnished to him independently by an inspector by whom they had been taken from an engine driving a pair of rolling mills in Staffordshire; and they were shown simply as specimens of what was being done in actual working in a particular case. No doubt they would not meet the views of steam users for regular work, because that engine had evidently not worked economically at the time when it was taking full steam throughout the whole stroke. But in order to get the same work done while cutting off say at half stroke, it would have been necessary to build an engine 50 per cent. larger; instead of which in that case the smallest engine was wanted that would be capable of doing the maximum work required. It must be remembered that the maximum diagrams (Fig. 6) did not represent the working of the engine throughout the whole day, but only at exceptional intervals when there was a heavy load in the mill; probably the average work would be represented by the middle diagram (CC, Fig. 7), in which the steam was throttled down considerably, the full-power diagrams being only exceptional ones.

The advantage which he claimed for the automatic expansion gear over the fixed expansion gear was that it gave the means of getting the effect of full steam throughout the whole stroke whenever there was the maximum work to be done, and at the same time the means of working the engine with the best economical expansion for any intermediate grades of work, especially for average work. With regard to the practical question of the efficiency of the particular valve described in the paper, there were many other valves he knew which, except for some small practical points, might be equally good. He did not wish therefore to represent this valve as absolutely the best of its kind, but simply to advocate the value of variable automatic expansion as a principle, especially in the case of a variable load, for which he considered this valve well suited. He concurred in the view that, where the load was uniform, variable automatic expansion

A 2

was of no use; the only case where it could be advantageously called into use was where the load varied considerably, the maximum horse power being say three times the minimum, and where that variation was continually going on.

With regard to leakage at the cylindrical expansion valve, if the ports were very long and narrow, extending for a considerable distance round the circumference, the leakage would probably be large; but where the ports extended only one-third round the whole circumference there was no appreciable leakage; the cut-off valve had a firm seating upon the back of the main slide-valve, and continued perfectly tight in working. With regard to the wear, he had seen the valve after it had been in use five or six years, and the faces were glassy and in good repair, and there was no leakage in working; the spindle was not rigid, but was so arranged as to allow the valve to follow its wear. The automatic expansion gear with right-and-left-hand screw, which had been referred to, was he thought open to the objection that the screw, working in the steam-chest, was liable to rust with standing and to become inoperative. In the valve described in the paper there was no moving gear inside the steam-chest; the turning gear and swivel joint was all outside, and the valve was a fixture upon its spindle. Moreover with the screw gear, for the extent of range from the extreme minimum or total closing of the port to the maximum cut-off at say 5-8ths of the stroke, some two or three complete revolutions of the screw were required, which was more than could well be got from the play of the governor balls; but with the valve described in the paper the same range of cut-off could easily be obtained with a turn of only 90 degrees of the valve spindle, which the rise and fall of the governor balls could readily effect.

With regard to the remark made in the paper about the loss due to the liquefaction of steam in expanding under work, the whole of the statement was to the effect that if the theoretical indicator diagram representing the economy to be derived from expansion were based upon the theoretical expansion curve, certain modifications would have to be introduced in calculating the real area of the diagram, in order to allow for practical losses. Among those modifications was the correction that had to be made in the theoretical curve for the

liquefaction which took place while work was being given off; it reduced the area of the indicator diagram, unless the heat so abstracted was made up by heat supplied from a steam-jacket.

The PRESIDENT moved a vote of thanks to Mr. Fell for his paper, which was passed.

The following votes of thanks were then moved by the President, and passed:—

1. To the Right Worshipful the Mayor of Bristol and the other Members of the Reception Committee for the cordial manner in which the Members of the Institution have been received in Bristol, and for the excellent arrangements made by them for the purposes of the Meeting, the inspection of machinery and manufacturing processes, and the organisation of the local Excursions.

2. To the Honorary Local Secretary, John C. Wilson, Esq., for his indefatigable and very successful exertions in providing for and accomplishing the objects of the Meeting.

3. To the Proprietors of the several Works in Bristol and the neighbourhood obligingly opened by them to the inspection of the Members of the Institution.

4. To the Chairman and Officers of the Great Western Railway Company for the special privileges granted in the Excursions, and for their hospitable entertainment of the Members.

5. To the Master Merchant Venturer, Charles B. Hare, Esq., and the Committee of the Society of Merchant Venturers, for their kindness in granting the accommodation of the Merchant Venturers' Hall, and other obliging facilities afforded by them for the President's Conversazione.

The Meeting then terminated.

EXCURSIONS.

On Tuesday afternoon, 24th July, the following Works in Bristol were opened to the visit of the Members:—

Avonside Engine Works, . . .	Avon Street.
Baker's Flour Mills, ...	Redcliff Backs.
Bristol Wagon Works, ...	Lawrence Hill.
Coalbrookdale Iron Warehouse, . .	Castle Street.
Derham's Shoe Factory, ...	Barton Street.
Evans' Avonside Tannery, . . .	St. Philip's Marsh.
Fox Walker and Co.'s Engine Works, .	St. George's.
Fry's Chocolate Works, . . .	Union Street.
Gas Works, ...	Canon's Marsh.
Do.	Avon Street.
Hare's Floorcloth Factory, . . .	Temple Gate.
Netham Chemical Works, . . .	Netham.
Panther Lead and Silver Works, .	Avon Street.
Rogers' Brewery, ...	Old Market Street.
Schweppe's Soda Water Manufactory,	Castle Street.
Thomas' Soap Works, ...	Broad Plain.
Wills' Tobacco Factory, . . .	Redcliffe Street.

On Tuesday evening the Members of the Institution, together with a numerous company of ladies and gentlemen resident in the neighbourhood, were entertained by the President and Mrs. Hawksley at a Conversazione in the rooms of the Merchant Venturers' Hall, which were kindly lent for the occasion by the Master Merchant Venturer, Charles B. Hare, Esq. A collection was exhibited of engineering models and specimens of manufacture &c., kindly lent for the occasion by Members and other gentlemen, some of whom obligingly attended to give personal explanations and illustrations to the visitors.

On Wednesday afternoon, 25th July, an Excursion was taken to Clifton Suspension Bridge, Leigh Woods, Durdham Down, and on to Penpole Point, from which a view was obtained of the Portishead and Avonmouth Docks and the site of the Severn Railway Tunnel.

In the evening a number of the Members and their friends dined together at the Grand Hotel.

On Thursday, 26th July, an Excursion was made by free special train and steamer, kindly granted by the Great Western Railway Co., to visit the Severn Tunnel Works at Portskewet, where one of the resident engineers, Mr. Geach, showed in operation his Rock-drilling Machine that had been described by him in a paper at the meeting; and the air-compressors and pumping machinery employed in the Tunnel works were also seen. With the rock-drilling machine a $1\frac{1}{2}$ in. hole was drilled at the rate of 12 in. per min. in a piece of the hard grey sandstone ("Pennant") rock from the tunnel excavation, the machine working with compressed air at 60 lb. pressure.

A trip down the Bristol Channel was then taken, and the Members were hospitably entertained at luncheon on the special steamer.

The Portishead Docks in progress of construction were then visited, and the works were shown by the resident engineer, Mr. Barbenson; these docks are in communication with Bristol by the Portishead Branch of the Great Western Railway, broad gauge.

The Avonmouth Docks were then visited, the Members being received by the managing director, Mr. Hew Dalrymple, and the engineer, Mr. Brunlees; these docks have been opened half a year, in connection with Bristol by the Avonmouth and Clifton Extension Railway, narrow gauge.

The Members returned to Bristol by the special steamer up the River Avon, past St. Vincent's Rocks and the Clifton Suspension Bridge.

On Friday, 27th July, an Excursion was made by a free special train to visit the Great Western Railway Locomotive and Carriage Works at Swindon, through which the Members were conducted by the Chairman of the Railway Co., Sir Daniel Gooch, and the locomotive superintendent, Mr. William Dean; and they were handsomely entertained at luncheon in the works.

The special train conveying the Members to Swindon was fitted with Sanders' Automatic Vacuum Brake, applied to most of the vehicles in the train, and its action was illustrated by some quick stoppages at high speed that were made in the course of the trip.

SAFETY VALVES.

Fig. 1. *Ordinary Safety Valve*

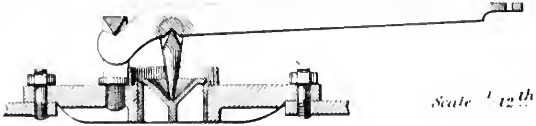
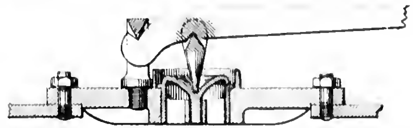


Fig. 2.



Scale 1/12th

Fig 3. *Ordinary Dead Weight Valve*

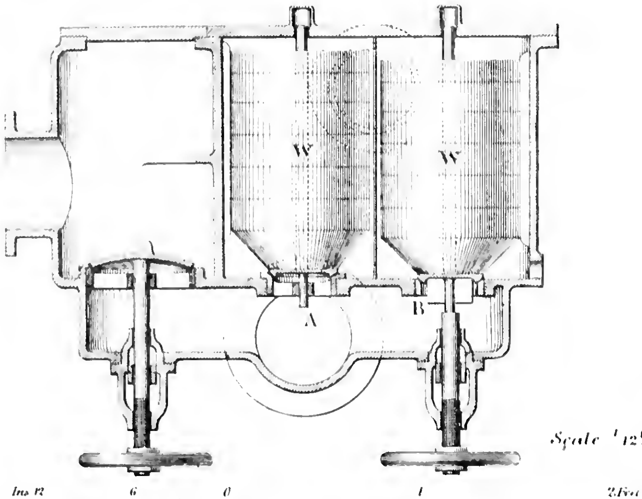
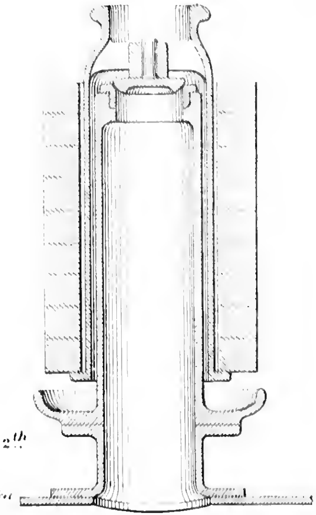
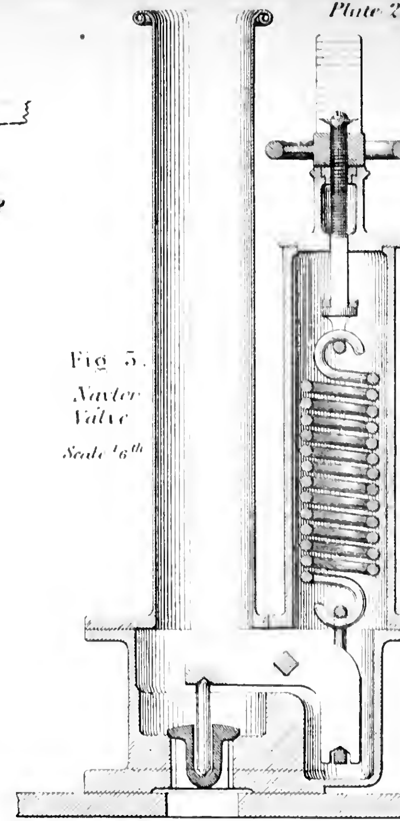


Fig 4. *Cowburn Valve.*



Scale 1/12th

Fig 5. *Naylor Valve* *Scale 1/6th*



(Proceedings Inst. M. E. 1877.)

Plate 22.

Klotz Valve for stationary boiler.

Fig. 6. Fig. 7.

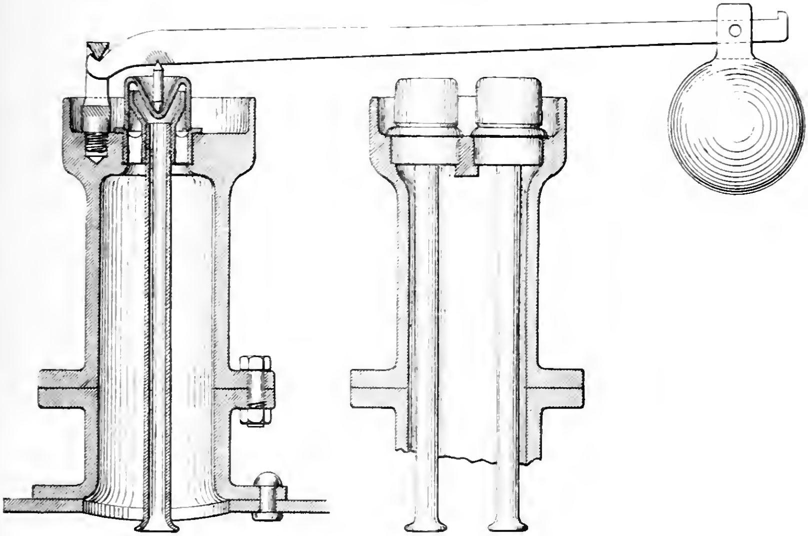
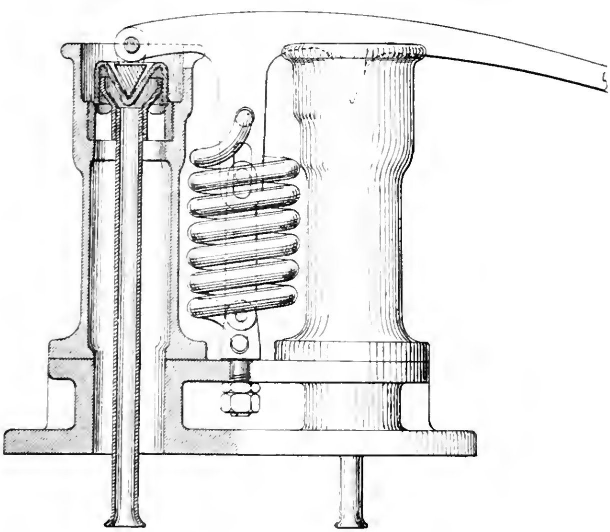


Fig. 8. *Klotz Valve with Ramsbottom lever.*



(Proceedings Inst. M. E. 187[illegible] *Scale 1/8th*

Ins. 12 6 0 *1 Foot*

SAFETY VALVES. *Plate 24.*

Klotz Valve for marine boiler.

Fig. 9. Fig. 10.

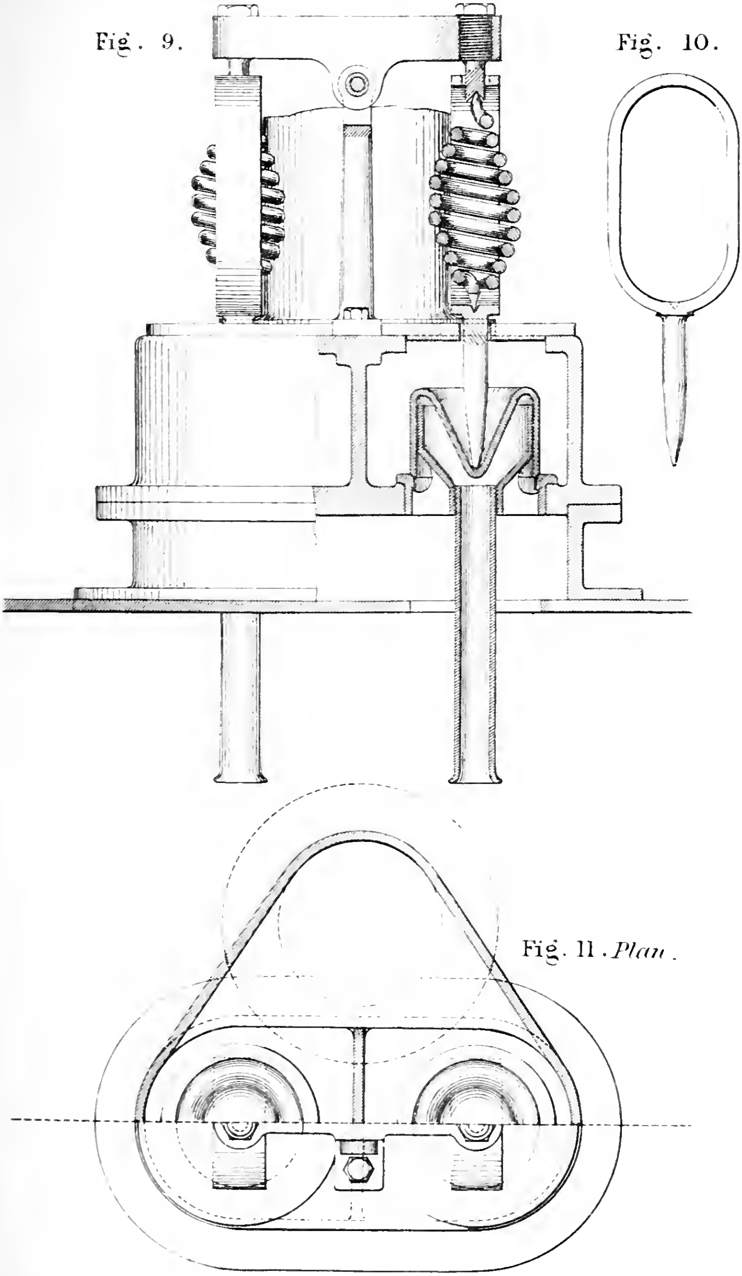


Fig. 11. *Plan.*

Scale $\frac{1}{6}$th 0 3 6 9 12 *Inches.*

(Proceedings Inst. M. E. 1877.)

SAFETY VALVES.

Plate 25.

Fig. 12. *Klotz Valve for Locomotive boiler.*

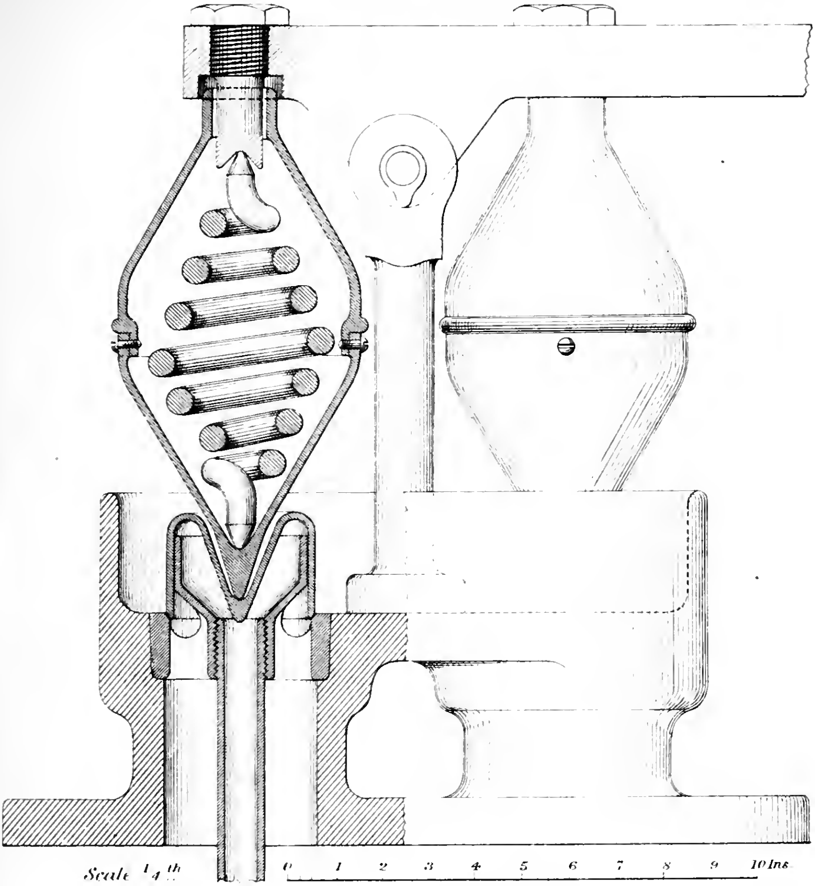
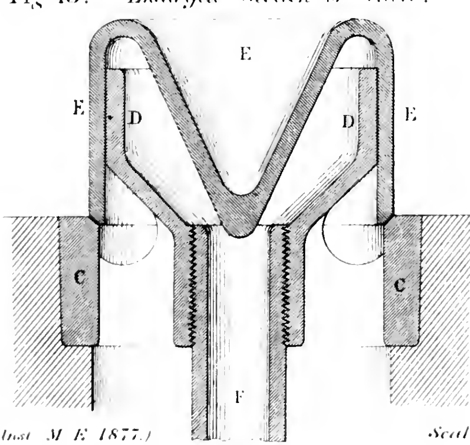


Fig 13. *Enlarged Section of Valve.*



(Proceedings Inst M E 1877.)

Scale 1/2

SAFETY VALVES.

"Paragon" Safety Valve.

Fig. 14.

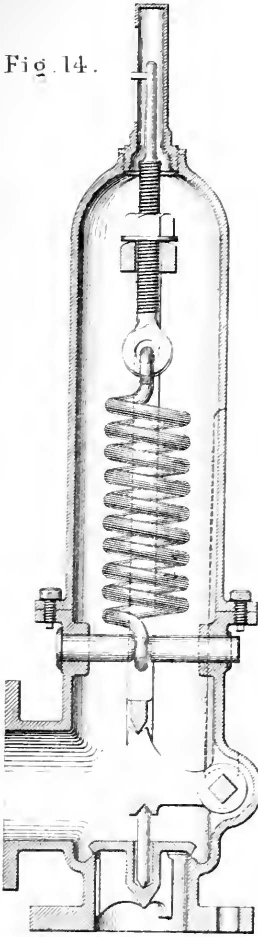


Fig. 15.

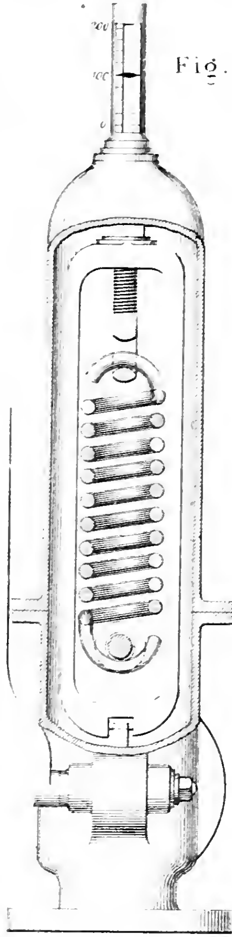


Fig. 16. Sectional Plan.

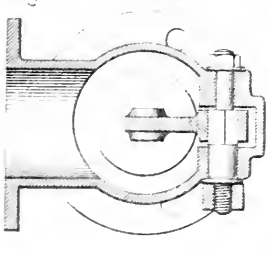
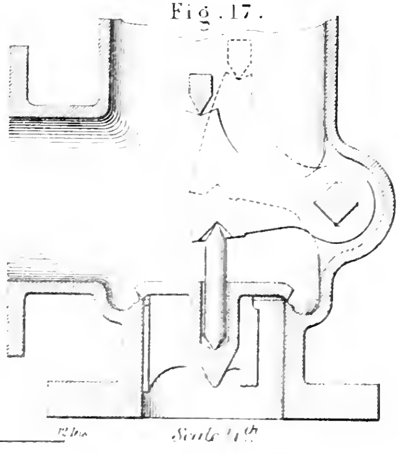


Fig. 17.



Scale 1/6 th

Scale 1/4 th

(Proceedings Inst. M. E. 1877.)

0 3 6 9 12 Ins

CIRCULAR SLIDE-VALVE.

Application
to
Outside-Cylinder
Express Passenger Engine.

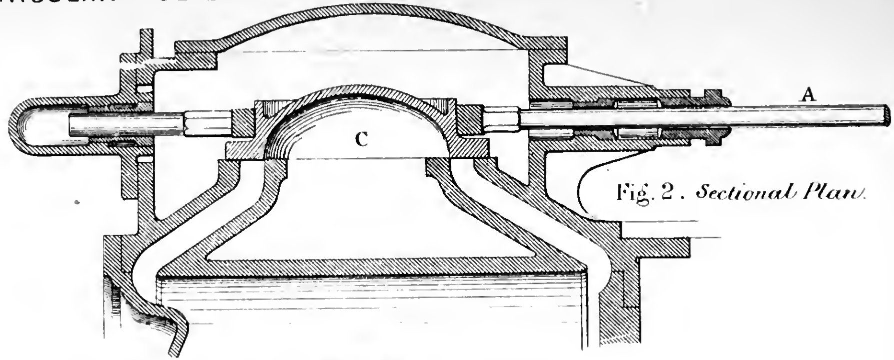
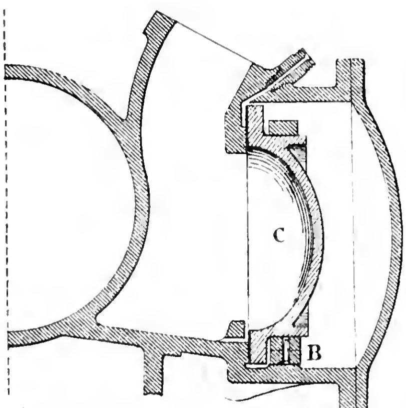


Fig. 2. *Sectional Plan.*

Fig. 1. *Transverse Section.*



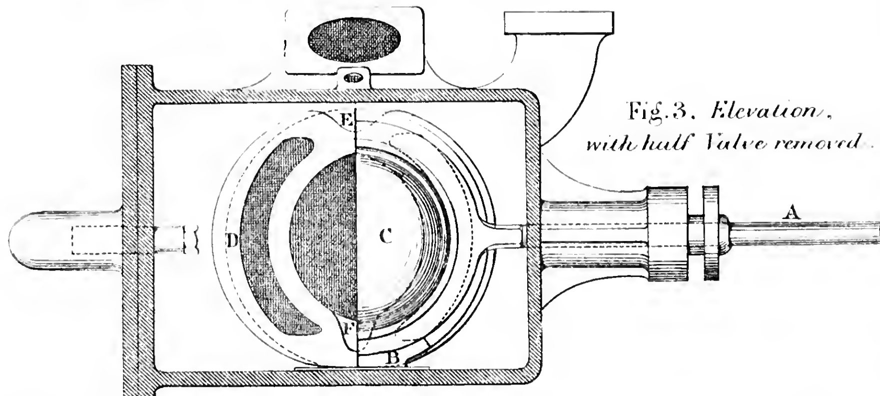


Fig. 3. *Elevation, with half Valve removed.*

Scale $^{1}/_{12}$*th*

Ins. 12 6 0 1 2 *Feet*

(*Proceedings Inst. M E 1877*

Plate 27.

CIRCULAR SLIDE-VALVE.

Application
to
Inside-Cylinder Locomotive.

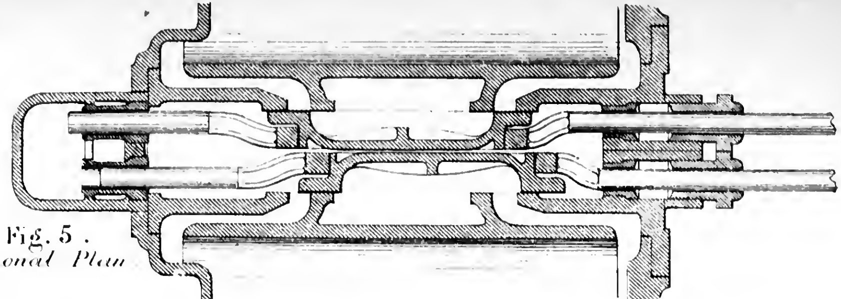


Fig. 5. *Sectional Plan*

Fig. 4. *Transverse Section.*

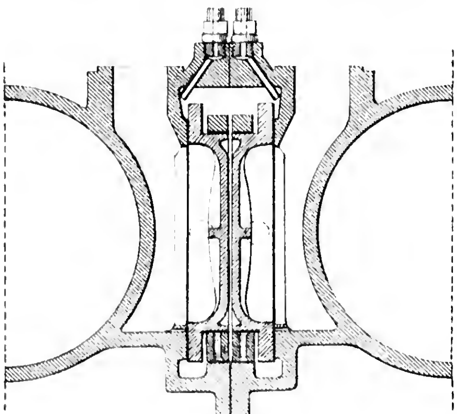
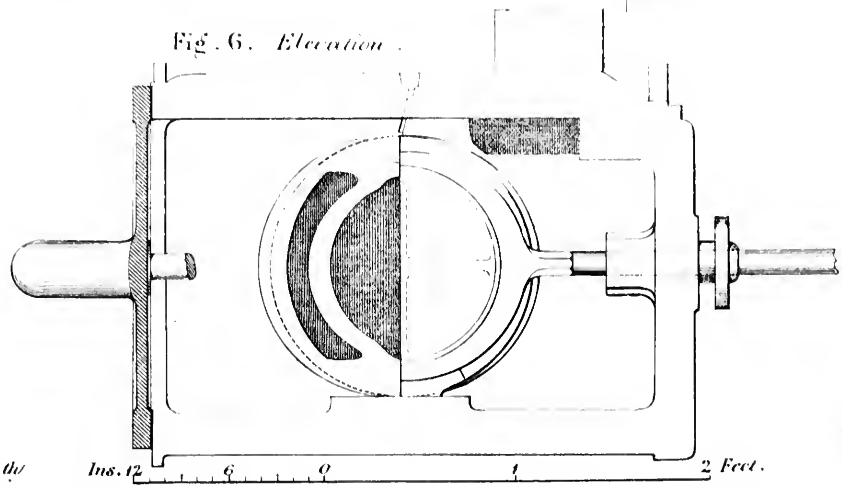


Fig. 6. *Elevation.*



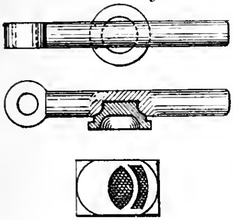
(*Proceedings Inst. M. E. 1877.*)

Scale 1/12th.

Plate 28.

CIRCULAR SLIDE-VALVE.

Fig. 7. *Slide-Valve for Armstrong Hydraulic Capstan Engine.*



Application to Three-Cylinder Hydraulic Capstan Engine.

Fig. 8.

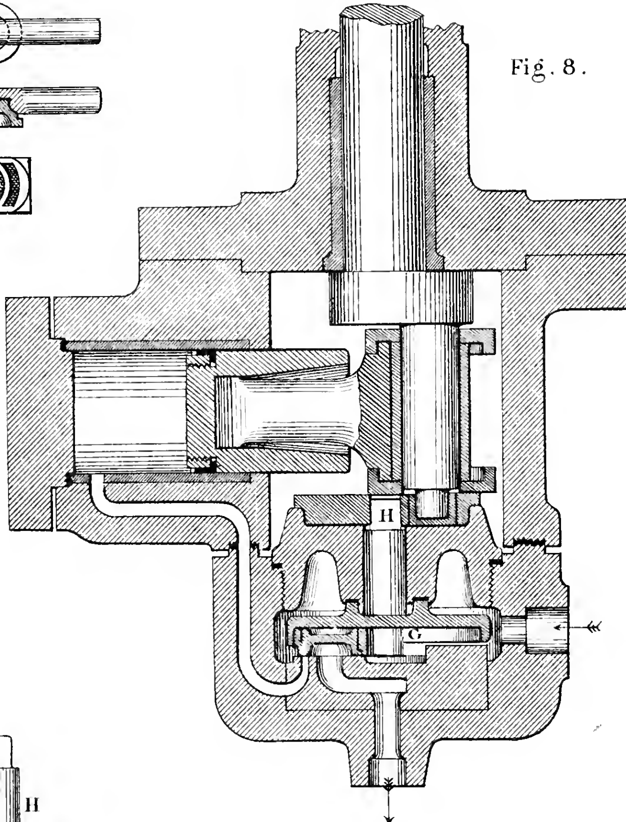


Fig. 10.
Valve.

Fig. 11.

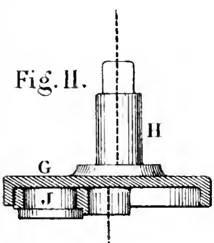


Fig. 12.

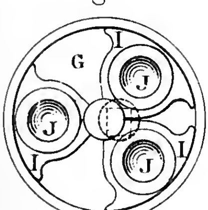
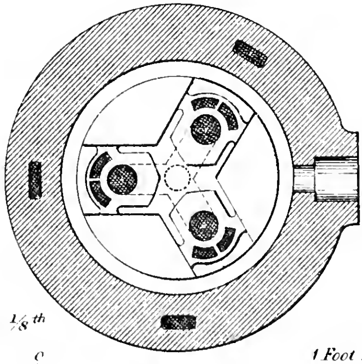


Fig. 9.



(Proceedings Inst. M.E. 1877.) *Scale 1/8th*

Ins. 12 6 0 1 Foot.

Allan's Balanced Slide-Valve for Passenger Locomotive.

Fig. 13. *Crewe 1844.*

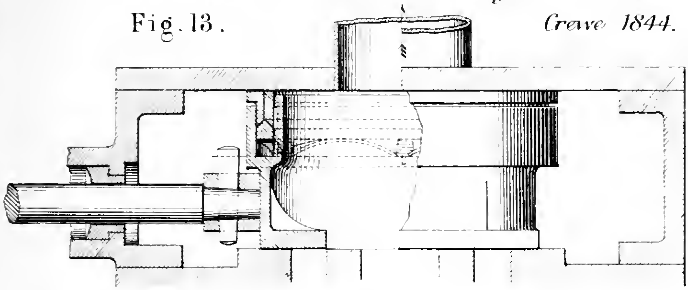


Fig. 14. *Plan.*

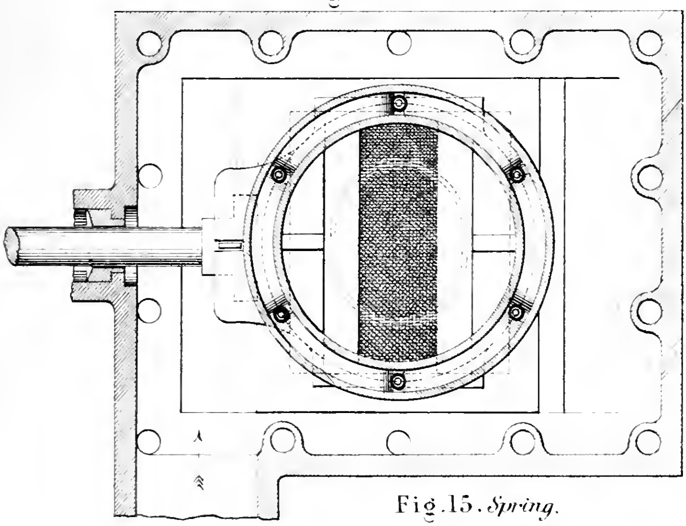


Fig. 15. *Spring.*

Balanced Circular Slide-Valve for Hydraulic Pressure.

Fig. 16.

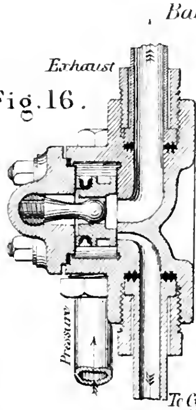
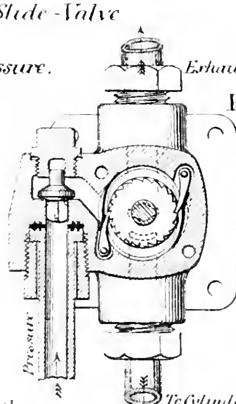


Fig. 17.



Scale 1/6th

0 6 12 Ins.

(Proceedings Inst. M.E. 1877.)

ROCK-DRILLING MACHINE.

Severn Tunnel Railway. Fig. 1. *General Section on line of Tunnel.*

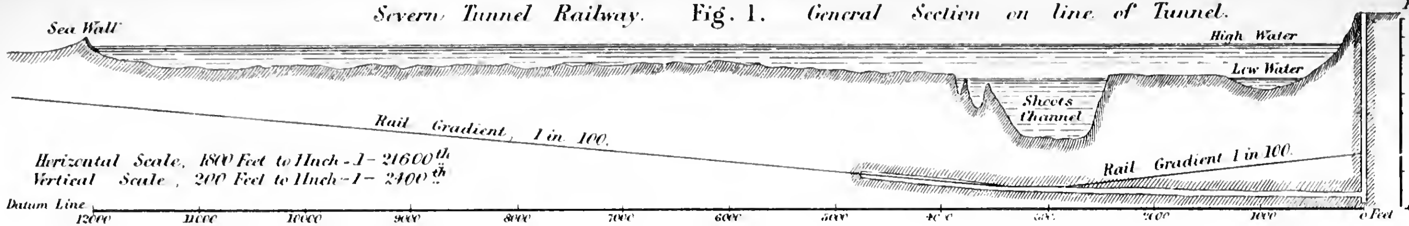
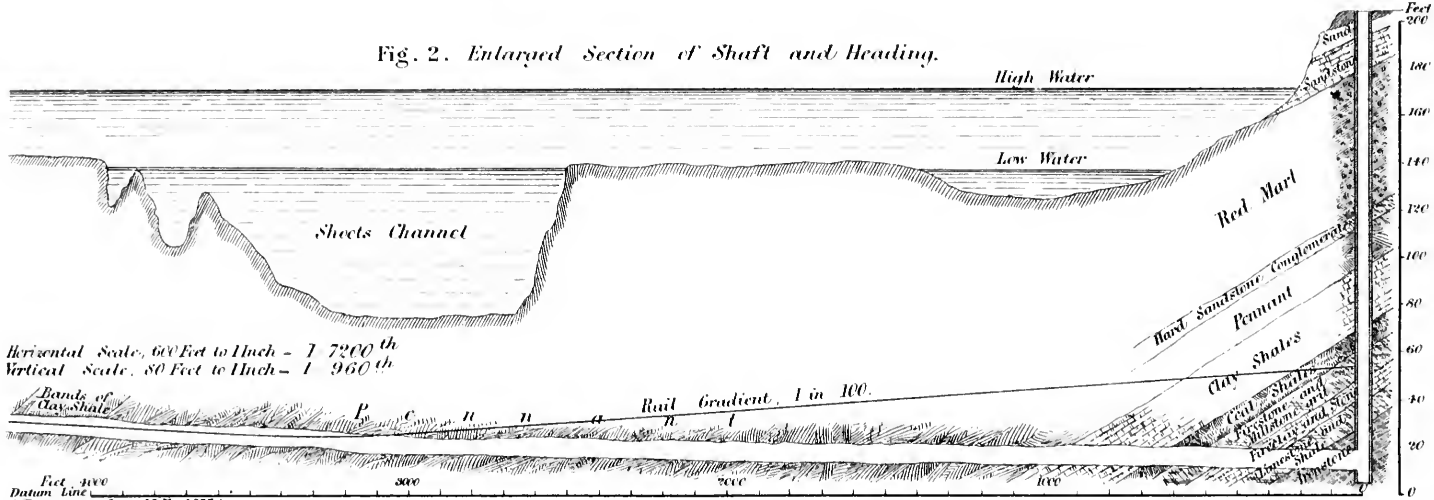


Fig. 2. *Enlarged Section of Shaft and Heading.*



(Proceedings Inst. M.E. 1877.)

Plate 31.

ROCK-DRILLING MACHINE.

Rock-Drilling Machine at Severn Tunnel Works.

Fig. 3. *Sectional Plan.*

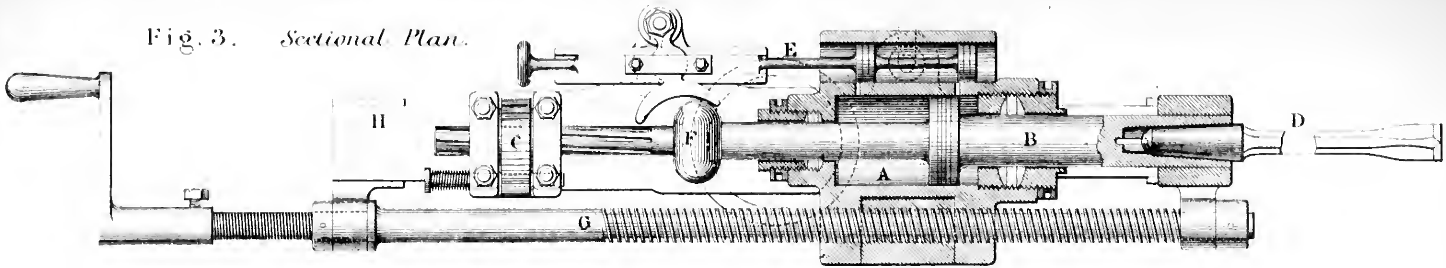
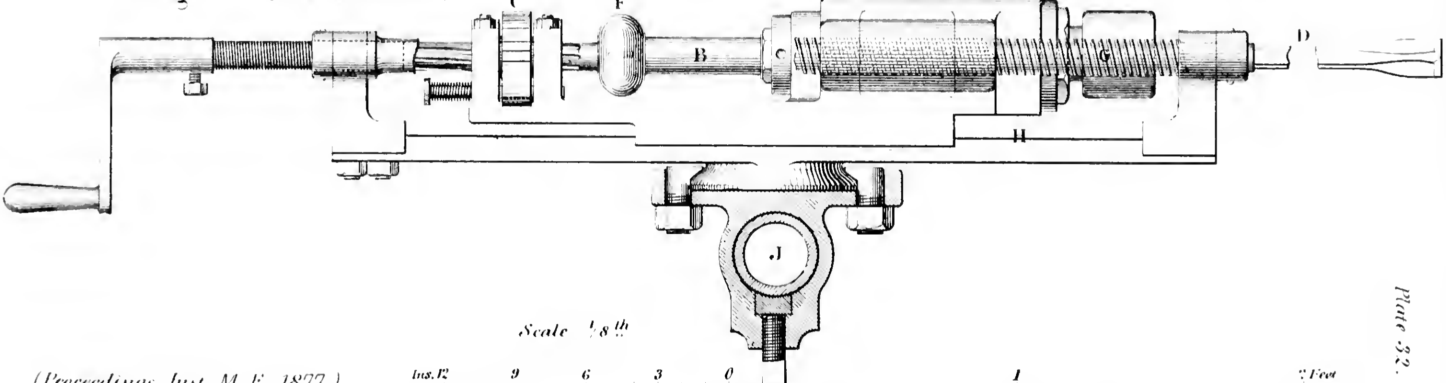


Fig. 4. *Side Elevation.*



(Proceedings Inst. M. E. 1877.)

Plate 32.

ROCK-DRILLING MACHINE.

Transverse Sections of Drilling Machine.

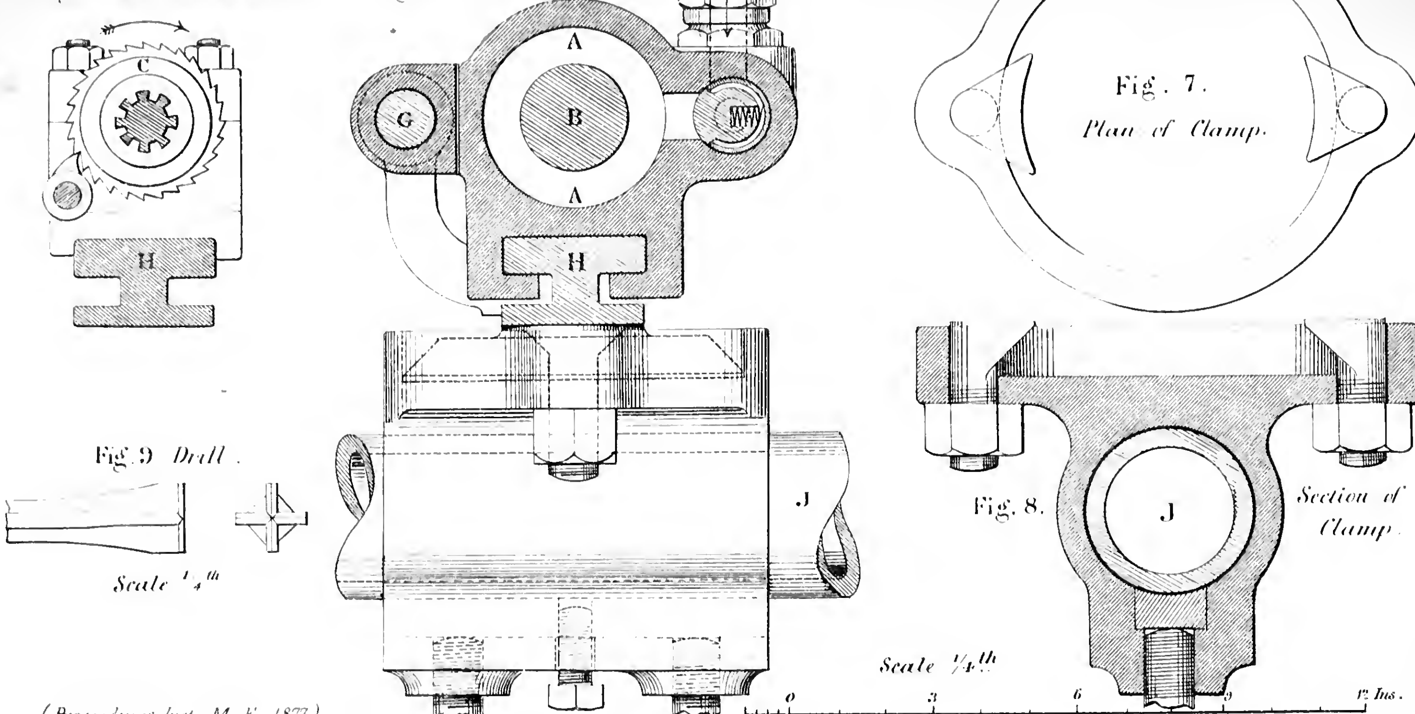


Fig. 5. *At Ratchet Wheel.*

Fig. 6. *At Drill Cylinder.*

Fig. 7. *Plan of Clamp.*

Fig. 8. *Section of Clamp.*

Scale 1/4th

Fig. 9 *Drill.*

Scale 1/4th

Plate 33.

ROCK-DRILLING MACHINE.

Drill Carriage.

Fig. 10. *Side Elevation*

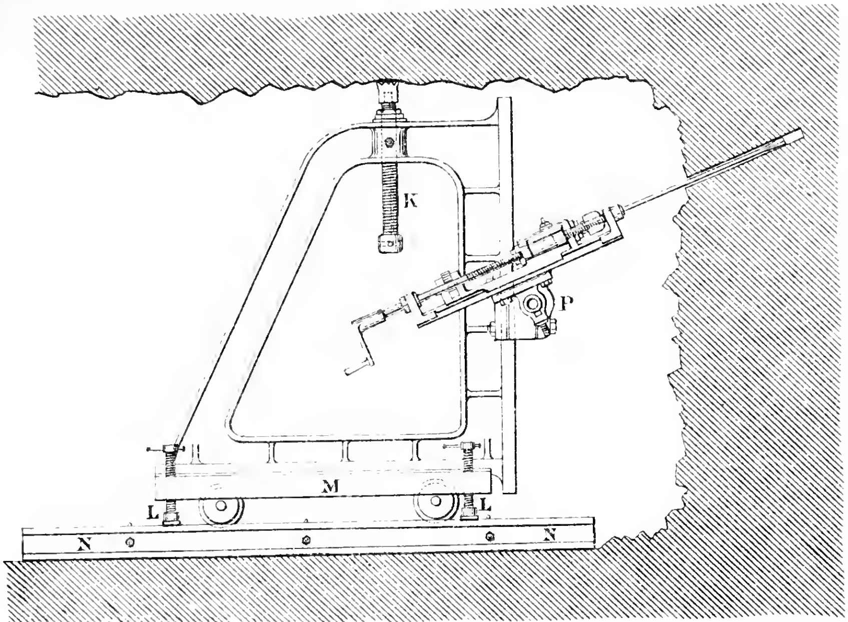
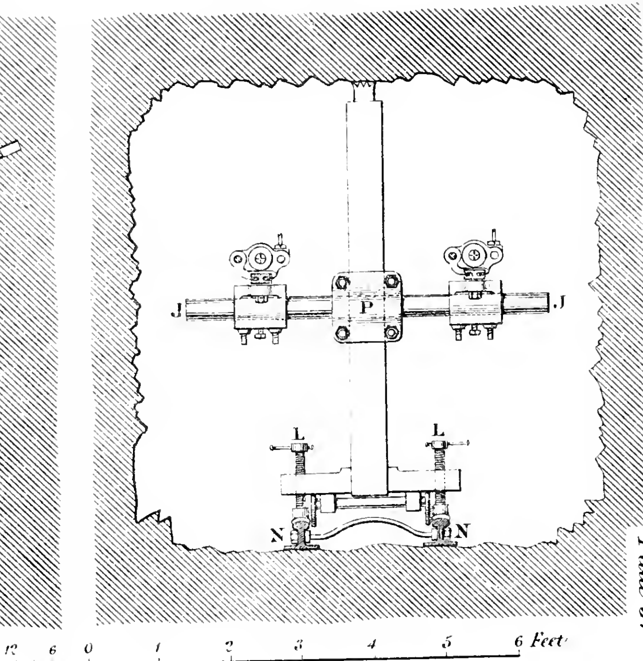


Fig. 11. *End Elevation.*



Scale 1/30th

(*Proceedings Inst. M E 1877*).

Plate 34

ROCK-DRILLING MACHINE.

Air Compresser.

Fig. 12.
Side
Elevation

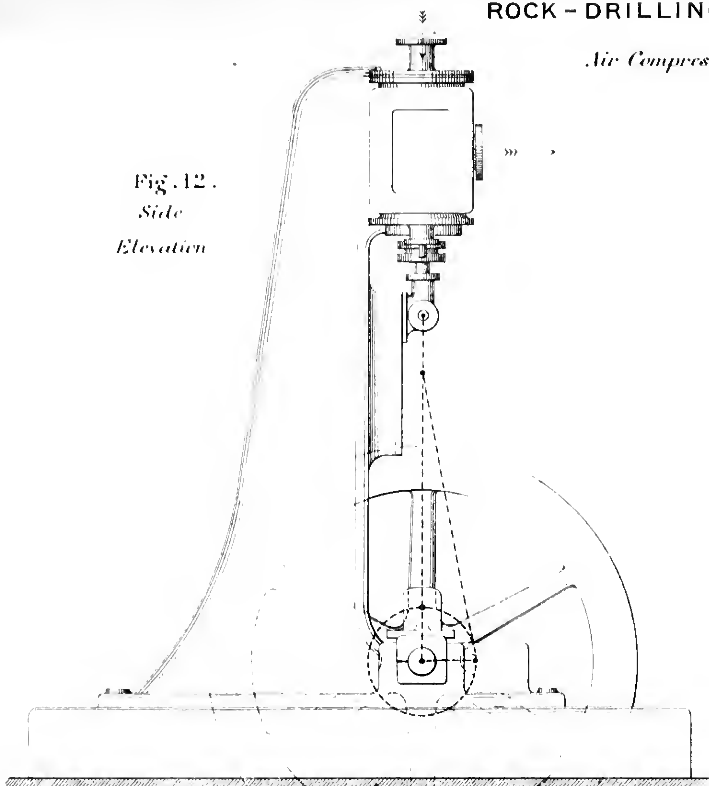
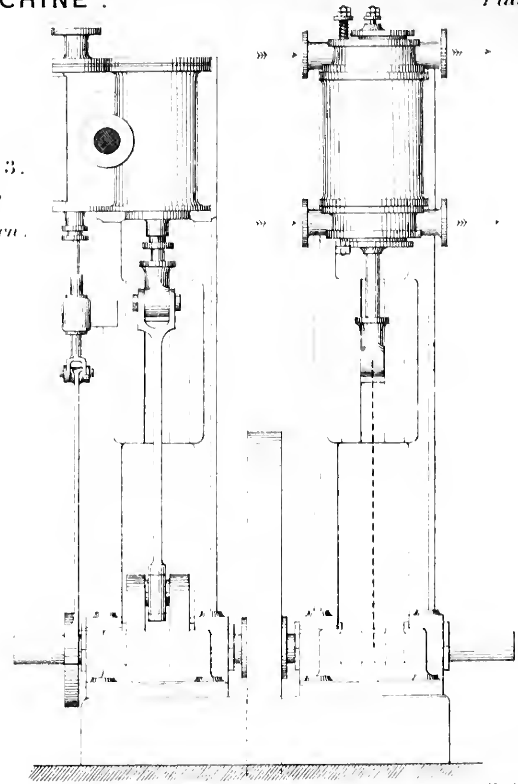


Fig. 13.
Front
Elevation.



Scale $^1/_{30}$th

Ins. 12 6 0 1 2 3 4 5 6 7 8 Feet

Plate 35.

ROCK-DRILLING MACHINE.

Air Compresser.

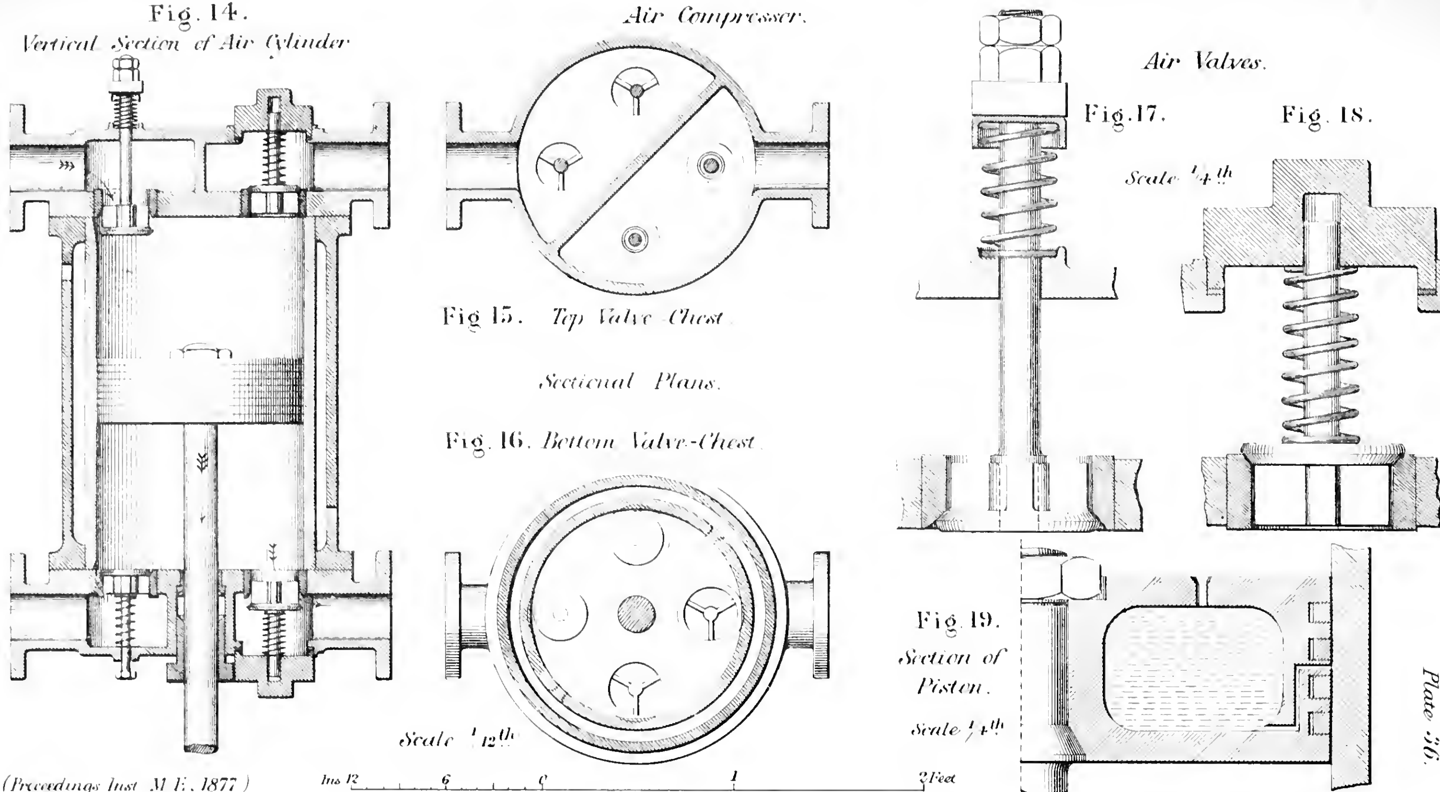


Fig. 14. *Vertical Section of Air Cylinder*

Fig 15. *Top Valve Chest.*

Sectional Plans.

Fig. 16. *Bottom Valve-Chest.*

Scale 1/12th

Air Valves.

Fig. 17.

Fig. 18.

Scale 1/4th

Fig. 19. *Section of Piston.*

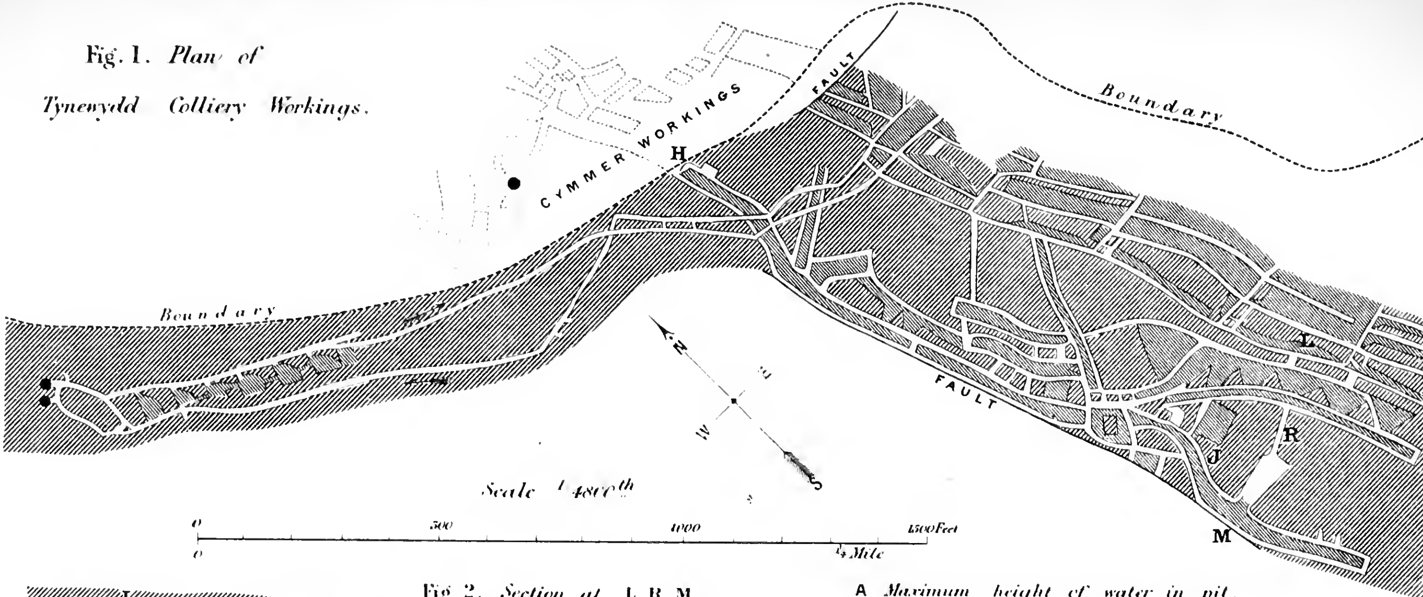
Scale 1/4th

(Proceedings Inst M E. 1877)

Plate 36.

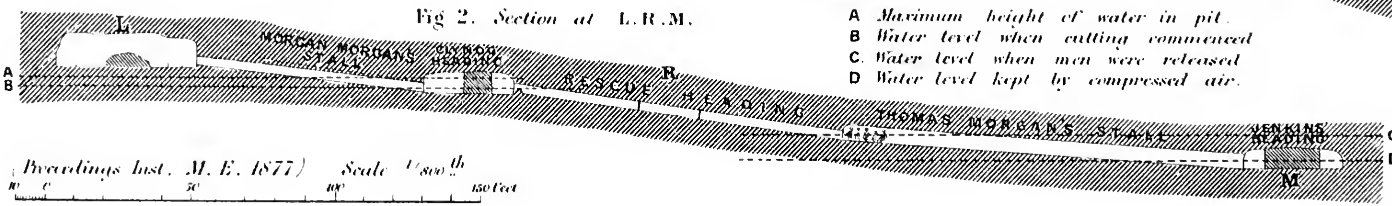
TYNEWYDD COLLIERY INUNDATION.

Fig. 1. Plan of Tynewydd Colliery Workings.



Scale 1/4800th

Fig 2. Section at L.R.M.



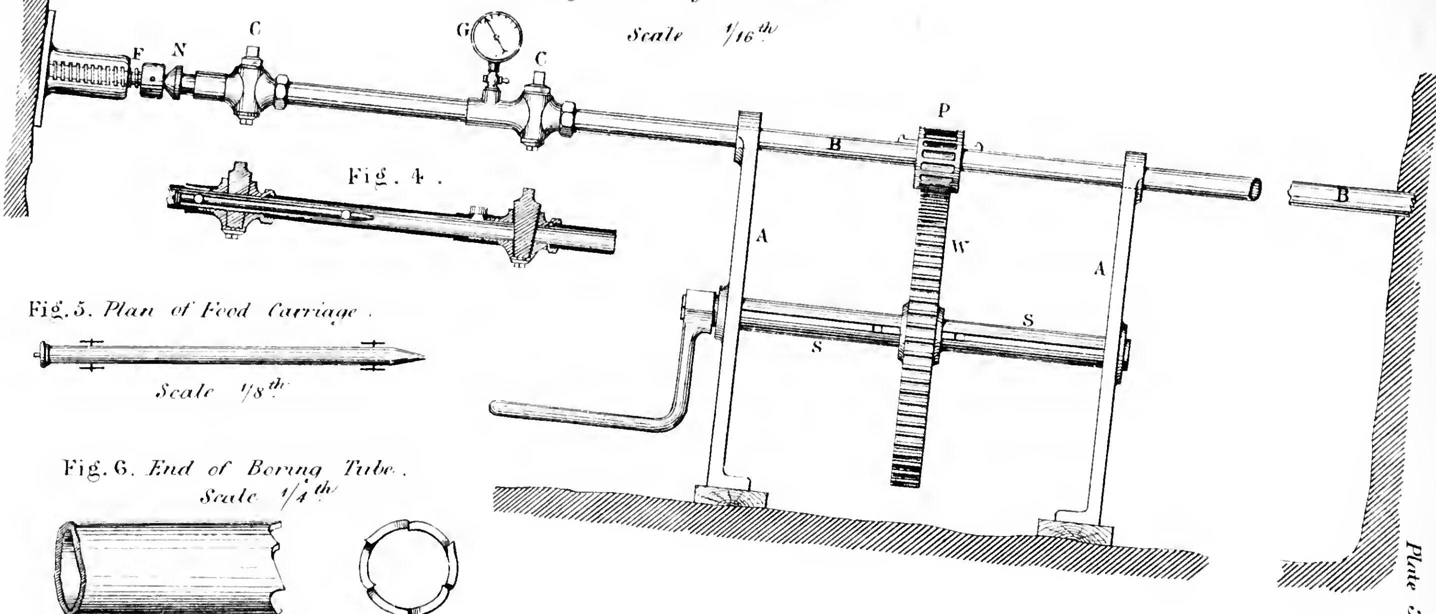
(Proceedings Inst. M. E. 1877) Scale 1/800th

Plate 37.

TYNEWYDD COLLIERY INUNDATION.

Fig. 3. *Boring Apparatus.*

Scale 1/16th.



Scale 1/16th. *Ins.* 12 6 0 1 2 3 *Feet.*

Fig. 4.

Fig. 5. *Plan of Feed Carriage.*

Scale 1/8th.

Fig. 6. *End of Boring Tube.*

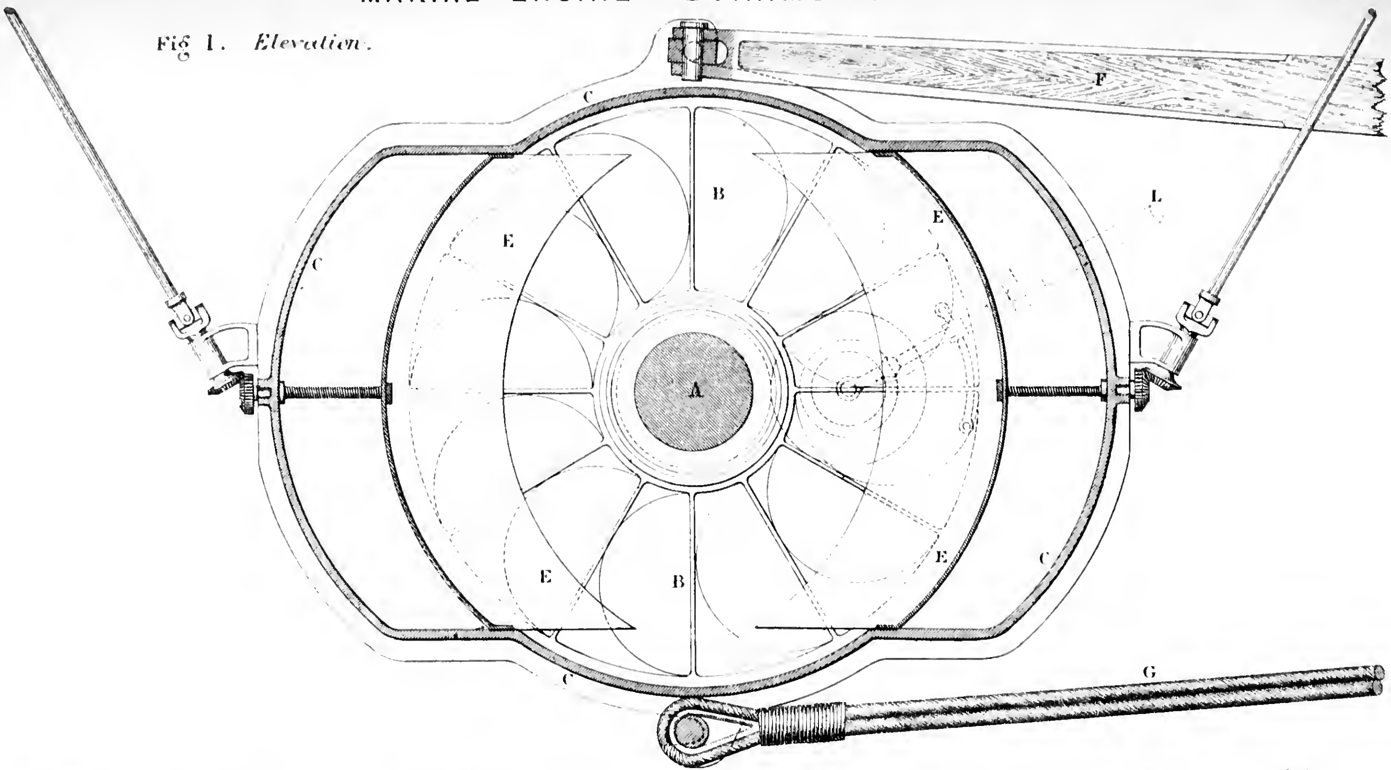
Scale 1/4th.

(*Proceedings Inst. M. E. 1877*)

Plate 38.

MARINE-ENGINE DYNAMOMETER.

Fig 1. *Elevation.*



(Proceedings Inst. M.E. 1877.)

Scale 1/20th

Ins. 12 6 0 1 2 3 4 5 Feet.

Plate 39.

MARINE-ENGINE DYNAMOMETER.

Fig. 2. *Transverse Section.*

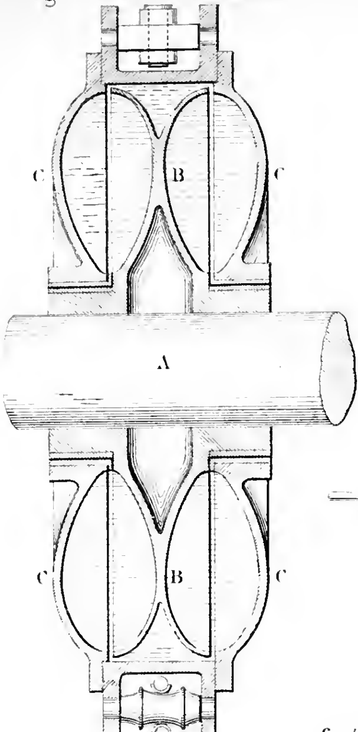


Fig. 4.

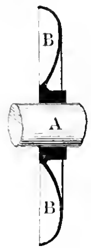


Fig. 5.

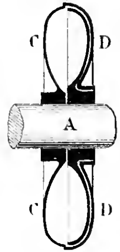
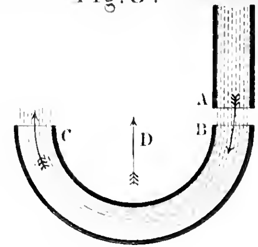


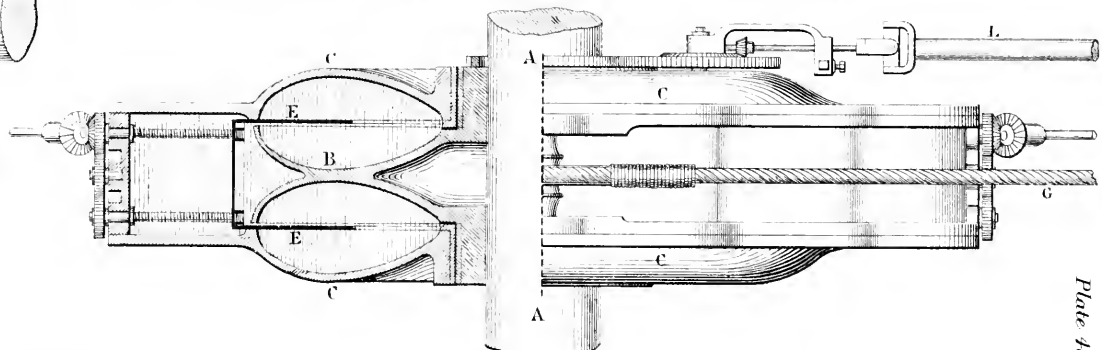
Fig. 6.

Fig. 7.

Fig. 8.



Half Horizontal Section (Inverted) Fig. 3. *Half Plan. (Inverted.)*



Scale 1/20th

Ins 12 6 0 1 2 3 4 5 Feet

(Proceedings Inst M E. 1877)

MARINE – ENGINE DYNAMOMETER.

Fig. 9. *Mode of application of Dynamometer for testing the Delivered Horse Power of Engines between 550 and 2000 H. P.*

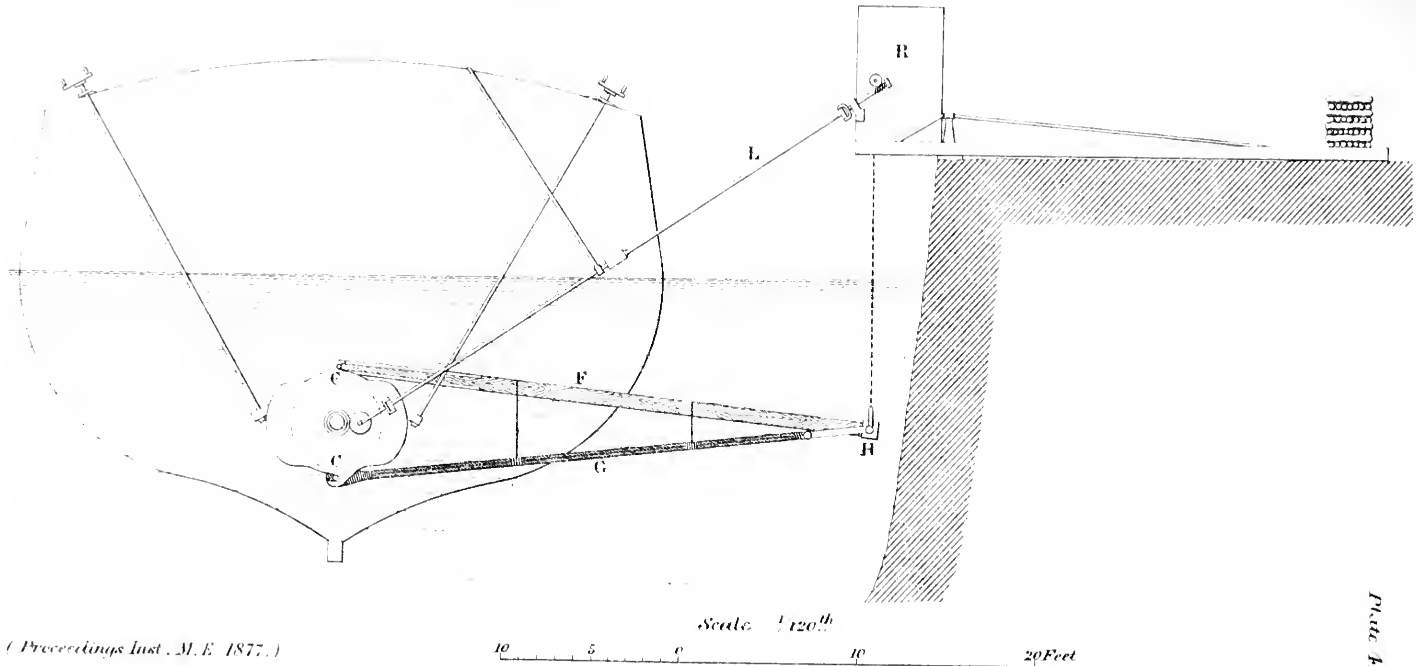


Plate 41.

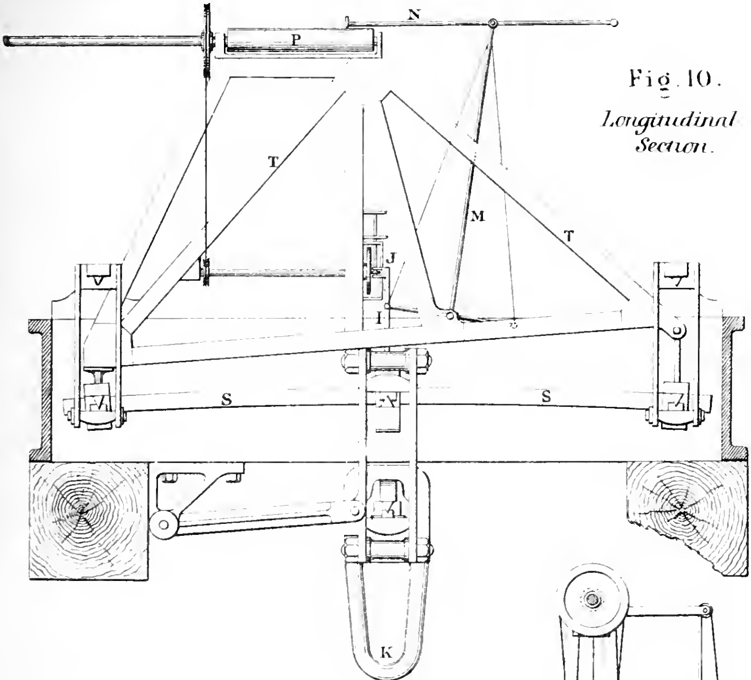


Fig. 10.
Longitudinal Section.

Fig. 11.
Transverse Section.

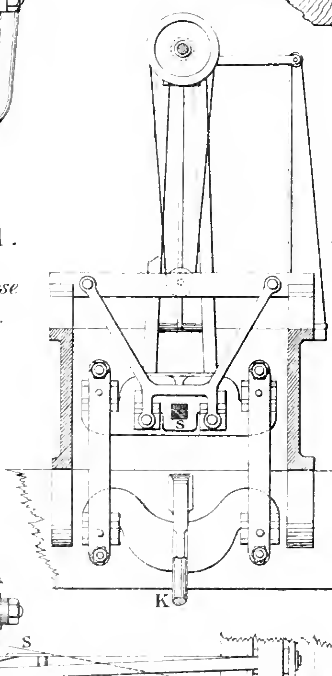
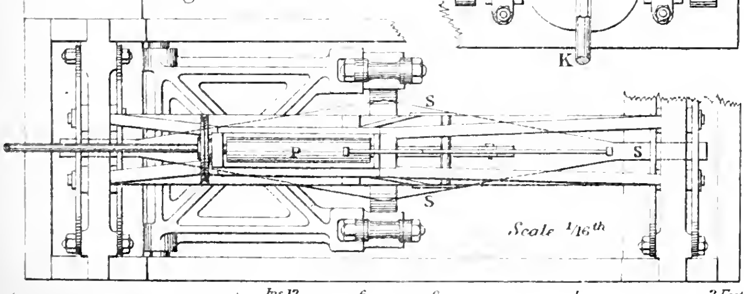


Fig. 12. *Plan.*



Ins.12 6 0 1 2 Feet

Diagrams to illustrate Appendix.

Fig. 1.

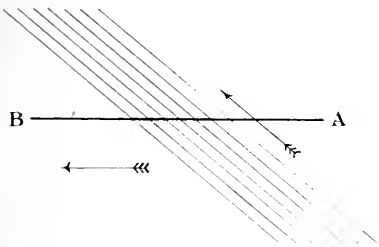


Fig. 2.

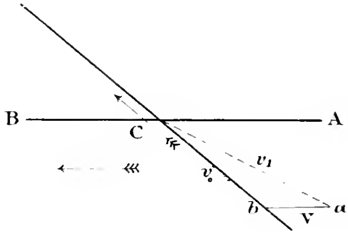


Fig. 3.

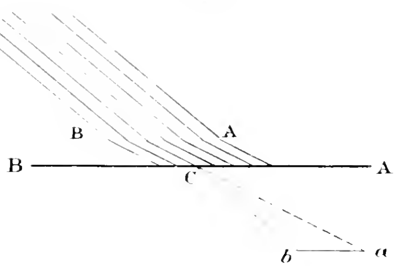


Fig. 4.

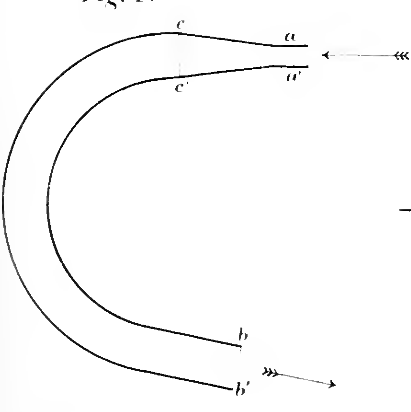
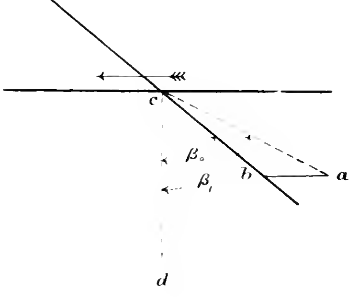


Fig. 5.



VARIABLE AUTOMATIC EXPANSION.

Rider's Variable Automatic Expansion Gear.

Fig. 1. *Elevation.*

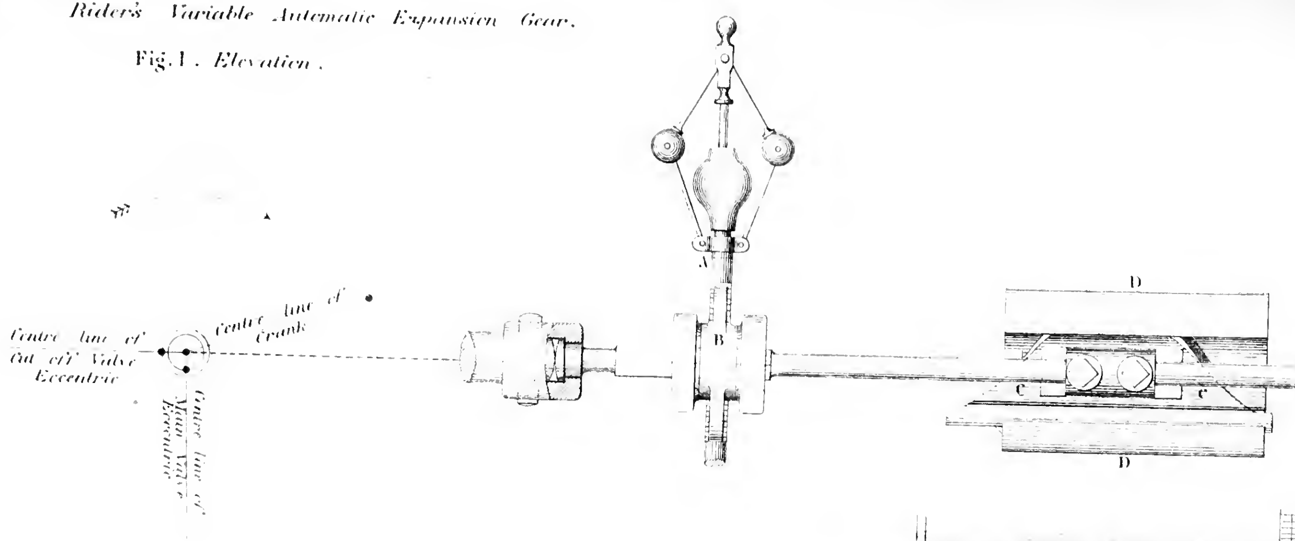
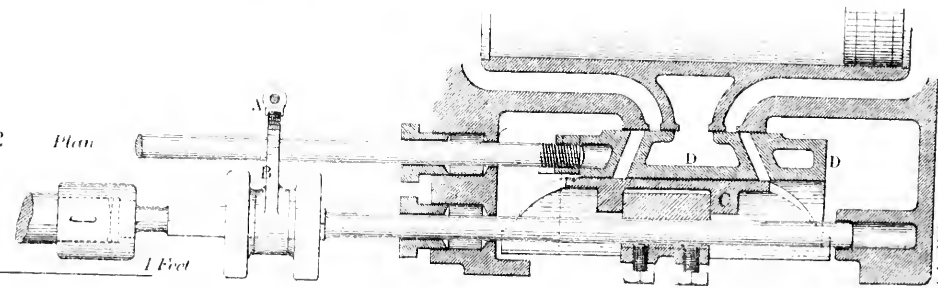


Fig. 2 *Plan*



Scale 1/8 th

Ins 12 9 6 3 0 1 Feet

VARIABLE AUTOMATIC EXPANSION.

Rider's Variable Automatic Expansion Gear.

Fig. 3. *Longitudinal Section of Valves.*

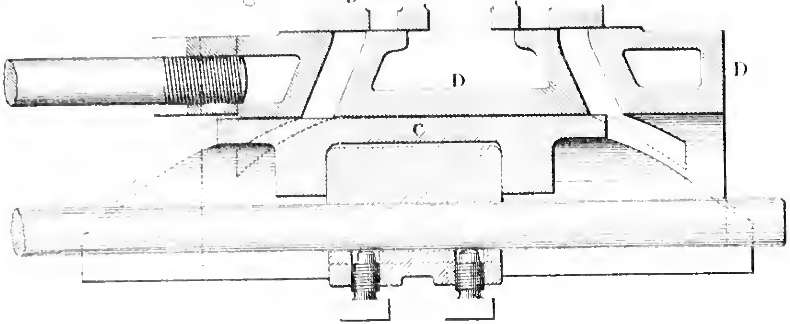


Fig. 4. *Plan of Valves*

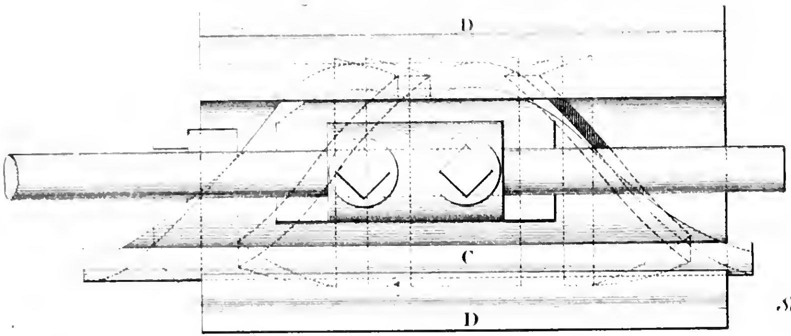
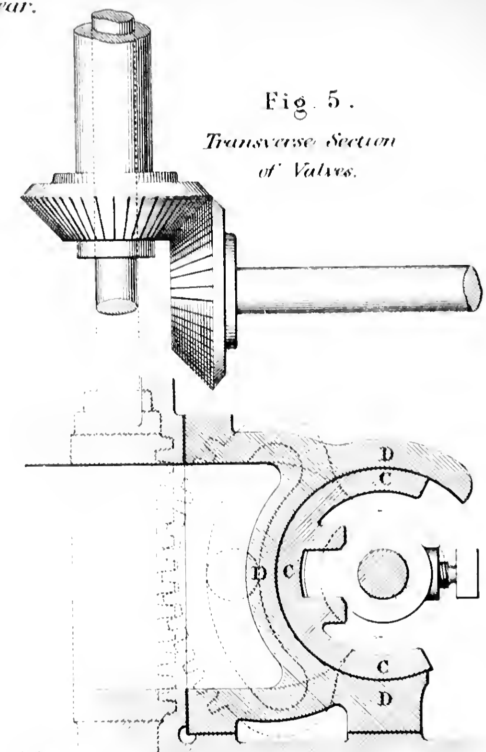


Fig. 5. *Transverse Section of Valves.*



Scale 1/4th

0 3 6 9 12 Inches.

Plate 45.

Indicator Diagrams from Rolling-Mill Engine without variable expansion gear.

Cylinder 12in. diam., 6ft. stroke.

Fig. 6. { AA *Both mills at work,* *18 rev. per min.* *319 Ind. H.P.*
BB *One mill with heavy load.* *23* .... *318* ....

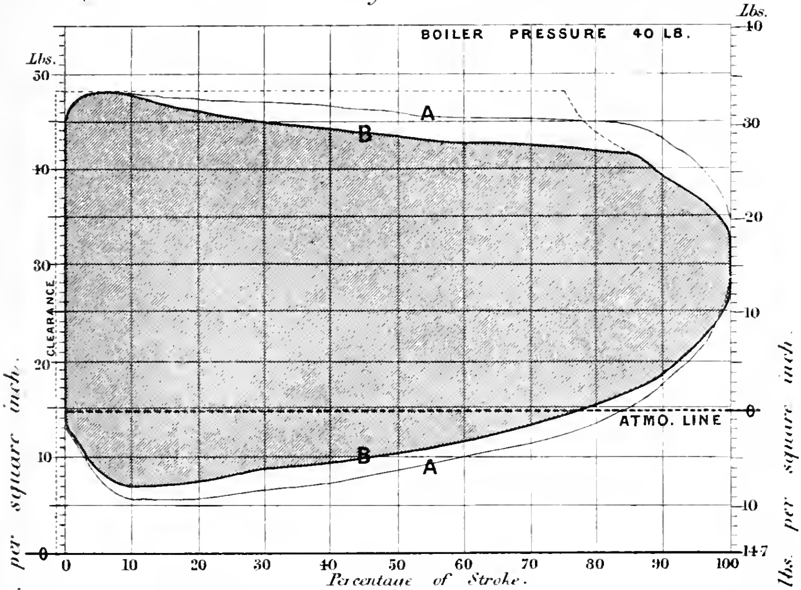
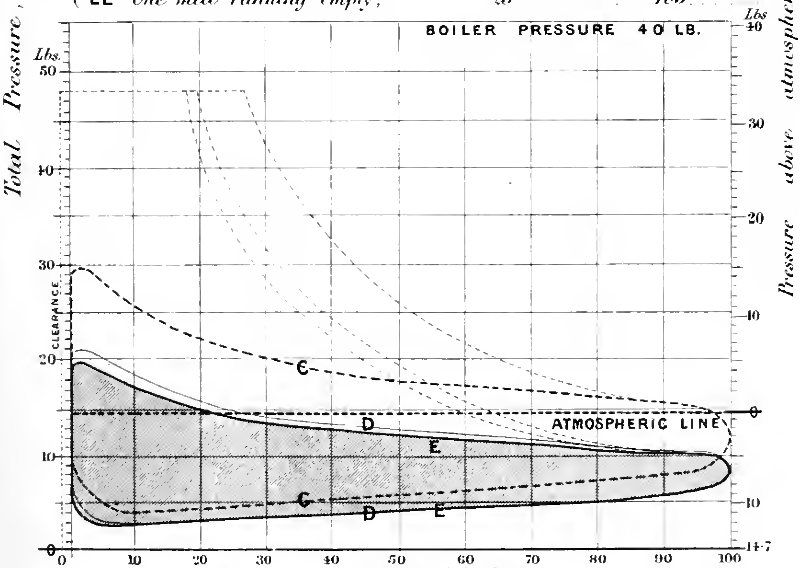


Fig. 7. { CC *One mill at work.* *23 rev. per min.* *156 Ind. H.P.*
DD *Both mills running empty,* *23* *122*
EE *One mill running empty,* *23* *103*



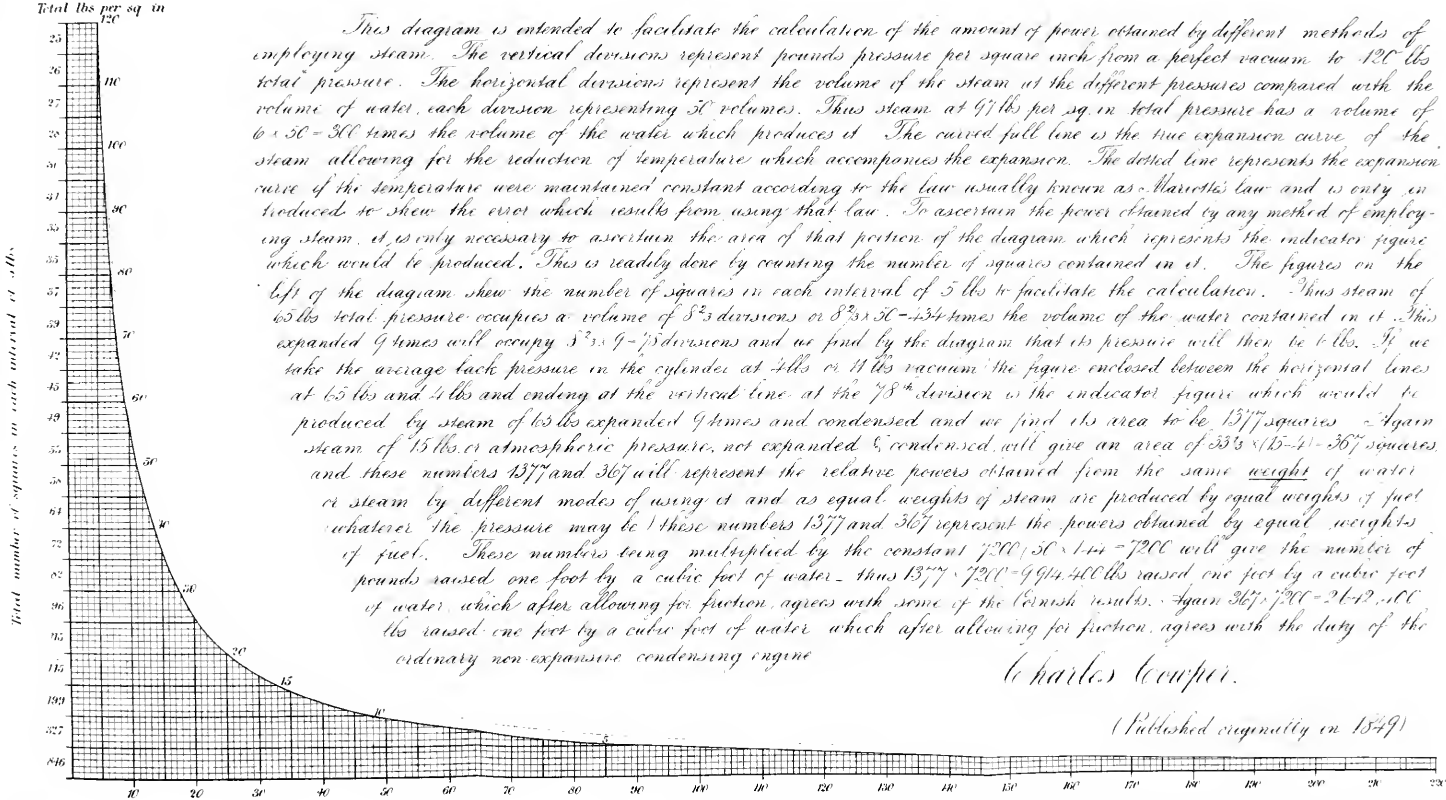
(Proceedings Inst. M. E. 1877.)

DIAGRAM OF THE TRUE EXPANSION CURVE OF STEAM.

This diagram is intended to facilitate the calculation of the amount of power obtained by different methods of employing steam. The vertical divisions represent pounds pressure per square inch from a perfect vacuum to 120 lbs total pressure. The horizontal divisions represent the volume of the steam at the different pressures compared with the volume of water, each division representing 50 volumes. Thus steam at 97 lbs per sq. in total pressure has a volume of 6 × 50 = 300 times the volume of the water which produces it. The curved full line is the true expansion curve of the steam allowing for the reduction of temperature which accompanies the expansion. The dotted line represents the expansion curve if the temperature were maintained constant according to the law usually known as Mariotte's law and is only introduced to shew the error which results from using that law. To ascertain the power obtained by any method of employing steam, it is only necessary to ascertain the area of that portion of the diagram which represents the indicator figure which would be produced. This is readily done by counting the number of squares contained in it. The figures on the left of the diagram shew the number of squares in each interval of 5 lbs to facilitate the calculation. Thus steam of 65 lbs total pressure occupies a volume of 8⅔ divisions or 8⅔ × 50 = 434 times the volume of the water contained in it. This expanded 9 times will occupy 8⅔ × 9 = 78 divisions and we find by the diagram that its pressure will then be 6 lbs. If we take the average back pressure in the cylinder at 4 lbs or 11 lbs vacuum the figure enclosed between the horizontal lines at 65 lbs and 4 lbs and ending at the vertical line at the 78th division is the indicator figure which would be produced by steam of 65 lbs expanded 9 times and condensed and we find its area to be 1377 squares. Again steam of 15 lbs. or atmospheric pressure, not expanded & condensed, will give an area of 33⅓ × (15 − 4) = 367 squares, and these numbers 1377 and 367 will represent the relative powers obtained from the same <u>weight</u> of water or steam by different modes of using it and as equal weights of steam are produced by equal weights of fuel (whatever the pressure may be) these numbers 1377 and 367 represent the powers obtained by equal weights of fuel. These numbers being multiplied by the constant 7200 (50 × 144 = 7200) will give the number of pounds raised one foot by a cubic foot of water — thus 1377 × 7200 = 9,914,400 lbs raised one foot by a cubic foot of water, which after allowing for friction, agrees with some of the Cornish results. Again 367 × 7200 = 2,642,400 lbs raised one foot by a cubic foot of water which after allowing for friction, agrees with the duty of the ordinary non-expansive condensing engine.

Charles Cowper.

(Published originally in 1849)



PROCEEDINGS.

November 1877.

The Autumn Meeting of the Members was held in the Memorial Hall, Albert Square, Manchester, on Wednesday, 7th November, 1877; Thomas Hawksley, Esq., President, in the Chair.

The Minutes of the last Meeting were read and confirmed.

The President announced that the Ballot Lists had been opened, and the following New Members were found to be duly elected:—

members.

William Phipson Beale,	London.
James Fletcher Burgess,	London.
John Chater,	London.
Arthur Cooper,	Sheffield.
George Cooper,	Buenos Ayres.
John Walter Davison,	Moscow.
Francis Howlett,	London.
John Imray,	London.
Christopher James,	Bristol.
John Paterson Smith,	Glasgow.
Francis Johnstone de Soyres,	Bristol.
John Spencer,	Westbromwich.
George Hurst Stanger,	Liverpool.
George Kelson Stothert,	Bristol.
Joseph John Tylor,	London.
John Watts,	Bristol.

graduates.

Arthur Heaton,	Birmingham.
Edward Homer Jeffreys,	Low Moor.

Lawrence Moore Kortright, ...	Holyhead.
Marion Harry Spielmann, ...	London.
William Thomas Grant Whitelock, .	Bradford.

The President announced that the President, Vice-Presidents, and five Members of Council in rotation, would go out of office in the ensuing year, according to the rules of the Institution; and that at the present meeting the nominations were to be made for the election at the Anniversary Meeting in January next.

The following Members were nominated accordingly by the Meeting:—

PRESIDENT.

John Robinson, ...	Manchester.

VICE-PRESIDENTS.

(Six of the number to be elected.)

Election as Member.		
1847.	Edward A. Cowper, ...	London.
1857.	William Menelaus, ...	Dowlais.
1858.	I. Lowthian Bell, M.P., F.R.S.,	Northallerton.
1858.	Charles Cochrane, ...	Stourbridge.
1859.	Daniel Adamson, ...	Manchester.
1859.	Charles P. Stewart, ...	London.
1860.	E. Hamer Carbutt, ...	Leeds.
1861.	Henry Bessemer, ...	London.
1862.	Francis W. Webb, ...	Crewe.
1862.	Percy G. B. Westmacott, ...	Newcastle.
1869.	Jeremiah Head, ...	Middlesbrough.
1873.	John Penn, Jun., ...	London.

COUNCIL.

(Five of the number to be elected.)

1856.	John Anderson, LL.D., F.R.S.E.,	London.
1859.	William Clay, ...	Birkenhead.
1859.	George B. Rennie, ...	London.
1863.	John C. Wilson, ...	Bristol.
1865.	David Greig, ...	Leeds.
1866.	Henry Chapman, ...	London.

1866. Henry Wren, ... Manchester.
1868. Arthur Paget, ... Loughborough.
1870. Anthony Bower, ... Liverpool.
1872. Henry H. Laird, ... Birkenhead.

The President mentioned that, with respect to the ballot lists for the election of the Vice-Presidents and Council, it was considered by the Council that it would be preferable, instead of arranging the names alphabetically as before, which often led to a kind of alphabetical selection, to place the names in the order of seniority as Members of the Institution, adding to each name the date of election as a Member, for the information of the Members voting.

The President announced that, in consequence of the removal of the head-quarters of the Institution to London, it would be necessary to revise the whole of the Rules and Bye-Laws, and to put the future of the Institution upon a more perfect legal footing; and during the time before the Anniversary Meeting the Council would give their attention to this subject, with a view to submit to the Members at that meeting a new set of rules and regulations, prepared under the advice of their Solicitor. With respect to one rule however it was necessary now to give notice of a very simple alteration; as the rules stood at present, the Treasurer of the Institution was required to be a banker in Birmingham, and as that could not be continued, it was necessary to alter the rules by omitting the words "in Birmingham," and allowing the Treasurer to be a banker anywhere. He accordingly gave notice that this alteration would be proposed at the next meeting of the Institution. Two notices for alterations of the rules had also been received from Members; but as the subject matters of these would be taken into consideration by the Council when engaged in framing the new rules, perhaps under those circumstances the notices would be withdrawn. He supposed there would be a whole code of rules and regulations to be submitted to the Members at the next meeting, and the Council would of course take the subject matters of these notices into their consideration.

Mr. A. Paget remarked that, if the notices were accepted at this meeting, the subjects of them could be discussed and action taken thereon at the next general meeting; but he did not see how any action could be taken then, unless the notices were given now.

Mr. R. Price Williams thought, with regard to the notice which he had handed in, that the matter would in no way be prejudiced if this was accepted as a formal notice. He accordingly gave notice that at the anniversary meeting in January he should propose "such alterations of the Rules and Bye-Laws of the Institution as would enable Members to vote on questions of importance without being required to attend the meetings at which any such questions might be considered or determined." His object in mentioning this now was that, if nothing should be done between the present meeting and the anniversary meeting in January, he might have an opportunity of then bringing on a substantive motion to that effect.

Mr. E. J. C. Welch said that, after the remarks which had been made by the President, he would forego bringing forward the notice he had intended to give.

The President announced that the Council had decided that the next Summer Meeting of the Institution be held in Paris, and had appointed a committee for making the necessary arrangements for that purpose; and those arrangements would, as far as possible, be communicated to the Members at the anniversary meeting.

He had further to announce that the Council proposed to appoint Mr. Walter R. Browne to succeed Mr. Marshall as Secretary of the Institution.

Mr. E. J. C. Welch remarked that according to the rules it appeared that the Secretary should be elected by the Members, and thus the appointment just mentioned should be brought before the General Meeting. He merely raised the question in order that the appointment might be made in legal form, and consistent with the rules.

The President said that, as there appeared to be some uncertainty in the wording of the rules upon the election of officers, it would be better to avoid all possible question by leaving it that Mr. Browne had been nominated by the Council for election at the anniversary meeting in January; when he had no doubt the Members would confirm the Council's nomination.

The following paper, communicated through Mr. John C. Wilson, of Bristol, was then read:—

DESCRIPTION OF IMPROVED RADIAL AXLEBOXES AND GUIDES.

By Mr. H. W. WIDMARK, of Bristol.

The well-known form of Radial Axleboxes with curvilinear sides and guides, in use in this country for upwards of fifteen years, afforded a means for the lateral and radial motion of the axle of locomotives while running round curves in the road, without resorting to the more cumbrous design of the two-wheel bogie with its girders, frames, arms, pins, turning and sliding castings; and while the first radial axlebox was simplicity itself, it was not without its inherent and attendant drawbacks.

The writer of the present paper has therefore been led to design another form of radial axlebox, in which exactly the same movements are obtained for the axle, while the former difficulties in manufacture are avoided, and the former objections to its proper working on a rough road are overcome. These axleboxes have been constructed at the Avonside Engine Works, Bristol, and several of them have been successfully in use in the United Kingdom and other countries for more than two years. The following is a description of this design, which is shown in Figs. 1 to 7, Plates 48 and 49.

Each pair of guides G G,—always cast in one piece, whether fixed to the main frames of the engine, as in Figs. 1 to 4, or to cross frames, as in Figs. 5 to 7,—is distinct from the other, and is bored to a cylindrical surface, the axis of which is in the same line as the spring pillar. An intermediate guide or box I I, the outer surface of which is turned so as to fit easily in the outer guide, can have a turning motion round its axis, and also an up and down motion, as may be required by the elasticity of the springs or the roughness of the road. The sides of the inclined passage through this piece are planed, and serve as a guide for the axlebox proper to work in. Both

the outer and the inner guides have their lower forks connected by horn stays H H to prevent springing.

The axlebox B has planed parallel sides, and is free to slide in a direction which is rectilinear and horizontal, but inclined to the axle of the wheels. The box at the opposite end of the axle is inclined in the opposite direction, as shown in Figs. 4 and 7; so that, when the wheels and axle deviate towards one side in consequence of the curvature of the road, the axle is simultaneously set in an oblique position to the engine frame, but radial to the road, one end being advanced in relation to the frame, whilst the other is drawn back by the inclined form of the axleboxes and the intermediate guides. Moreover, as the sides of the axleboxes are parallel planes, and as there are no flanges, the axleboxes are free to turn round a horizontal axis which is at right angles to these side planes. Thus one axlebox may rise and the other fall in the guides, as required by the state of the road. This very necessary motion is prevented when the sides of the boxes form parts of circles fitting to corresponding curvilinear surfaces on the guides; such boxes move freely only when they both stand at the same height in the guides, but would be in danger of jamming and fixing the axle if the oscillation of the engine or the irregularity of the road made one box rise more than the other.

In Fig. 1 is shown a frame with its guides in such an inclined relation to the wheels, axles, and radial axleboxes. In the writer's design each axlebox system becomes a universal joint; for there is a vertical turning of the inside guide in the outer guide, a horizontal turning of the axlebox in the inner guide, and also of course the turning of the axlebox round the axle; thus there is no possibility of the axle becoming jammed in the guides.

As in this design the axlebox travels in a direction which is rectilinear, it is easy to arrange inclined planes on the top of the box, and corresponding inclined planes on a sliding piece J, Fig. 1, which is held by the inner guide, and takes the thrust of the spring. By this means an elasticity is given to the axle, or a tendency to come back to a central position when not constrained by the curvature of the line. On a straight line the axle is locked by the inclined planes

just referred to; so that it becomes parallel with the other axles, whereby friction is prevented between the wheels and rails; in this way the engine is also steadied, the swinging action of the cylinders being prevented. One system of six inclined planes is shown in Figs. 1 and 4, and another system with only three planes in Figs. 6 and 7. In the first case the inclined planes are entirely above the box, Fig. 1, and are lubricated by separate oil pipes and grooves; in the latter case the inclines are placed over the box, Fig. 6, but at a lower level, so as to be surrounded by the upper flanges of the box, and are always immersed in a bath of oil, which is covered in and guarded from dust by fixed and sliding covers.

Mr. Widmark exhibited a specimen of the axlebox, and also a working model of a pair of axleboxes and axle, showing the action of the axleboxes in accommodating themselves to the radial position of the axle in running round a curve, and to any transverse inclination from the horizontal position. He showed that the axle was thus left quite free to move in any direction, and that each axlebox formed a universal joint upon the axle. He explained that in the case of a very narrow-gauge engine the axlebox guides were fixed on cross frames, which again were fixed on the main frames, as shown in Figs. 5 to 7, Plate 49, for a 2 ft. 6 in. gauge.

Mr. J. Robinson suggested that Mr. Webb might give some information on this subject, as he had used axleboxes intended to effect the same purpose as that described in the paper.

Mr. F. W. Webb said the first engine with radial axleboxes upon the London and North Western Railway was the "White Raven," built for the St. Helen's line, with Mr. W. Bridges Adams' radial axleboxes; it was an eight-wheel four-coupled engine, with the leading and trailing wheels left free to assume a radial position; but it was found to be so lively in running that it could not

be kept steady on a straight line. In the arrangement described in the paper the tendency to deviate from the straight line was of course controlled in some measure by the inclined planes on the top of the axlebox; but there was one disadvantage in that plan, namely the jerky motion it gave to the engine when running. There was also another objection in the fact that, when the engine passed round a curve, and the spring traversed to one side, all the pressure of the spring was brought upon one end of the journal, and he had found this in practice a very great defect. A further disadvantage also was that, when the engine was going round a curve and the spring pillar travelled up the inclined plane on the top of the axlebox, it put an extra pressure on the spring at the same time that the outer rail was elevated to throw the engine round the curve; and there was consequently a difference in the pressure upon the axlebox when passing round a curve and when running along a straight line. Looking at the drawings showing the arrangement of the axleboxes for a narrow-gauge engine (Figs. 5 to 7, Plate 49), it struck him that the axleboxes themselves were there so near together that it would be an advantage to apply the system he had adopted on the London and North Western Railway for a four-coupled six-wheel engine, which was free to everyone, and was shown in Figs. 8 to 12, Plate 50. In this case, instead of the two ordinary independent axleboxes for the leading wheels, one on each side of the engine, there was only a single long axlebox, in the form of a plain girder of cast iron A A, extending right across from side to side of the engine, and forming in plan a circular arc struck from a point half way between the driving and trailing axles. Two corresponding curved wrought-iron or steel plates B B, bolted to the engine main frames, encased the curved axlebox at front and back, but without any fitting whatever, the space between the two plates B B being about 1-8th inch wider than the cast-iron girder or axlebox A which worked between them. There was no necessity for any fitting, and the axlebox and plates would practically last for ever, as any little slackness did not matter; for when the engine was running forwards, the axlebox pressed against the front plate, and when backwards, against the other plate. The ordinary brass bearing was put in each

end of the long axlebox; and the spring pillar bore upon a plain footstep C sliding upon a flat surface in the grease box on the top of the axlebox. The axlebox being a rigid girder from end to end, the pressure upon the journals would not be affected by the spring pillars sliding laterally with the engine frame, but would be very much the same in any position in which the engine might be on a curve. The difficulty of lateral oscillation experienced in the first engine, the "White Raven," had been got over in the same way as by Mr. William Adams on the North London Railway, namely by putting side controlling springs. There was a centre stay across at D, which tied the front plate to the one behind; and on each side there was a stay across the axlebox at E E, with a bolt through all three stays, the hole in the middle one being sufficiently large to allow of the play of the axlebox; the bolt carried a pair of india-rubber buffing springs S S on each side of the centre stay, and these were made of such a strength that about 10 cwt. lateral pressure against the wheel flange was sufficient to throw the engine over towards either side to the full extent of the lateral movement allowed. It was found in practice that this plan answered the purpose very well. The first engine so constructed had been put to work in May of last year, and had been running the express between Manchester and Buxton, with leading wheels only 3 ft. diam., and up to the present time these had not required re-turning. He had now forty engines made on the same plan, with the same satisfactory results; many of them were working from the Manchester station. He had brought this plan before the notice of the members as being a simple and cheap method of getting over the difficulty experienced in going round a curve; it required no fitting, except for putting the two brasses into the ends of the axlebox girder.

Mr. R. Price Williams asked whether on a straight line there was not a tendency to accumulate lateral motion with that arrangement of side buffing springs.

Mr. F. W. Webb replied that the side buffing springs effectually kept the engine steady laterally. He mentioned that the total weight

of the axlebox girder and accompanying parts was 8·84 cwt.; and taking the weight of a pair of ordinary axleboxes at about 2 cwt., this practically made the engine only about $6\frac{3}{4}$ cwt. heavier than it would be with the ordinary fixed axle.

Mr. R. Price Williams asked whether in the axlebox described in the paper there was any arrangement to prevent the accumulation of lateral oscillation when running on a straight line. On a very well maintained piece of straight road on the Manchester Sheffield and Lincolnshire Railway he had noticed the drivers complained that it was impossible to keep the engine steady; but having got that portion of the line into the condition of a new road, where he considered there ought to have been the perfection of running, he discredited their complaint, until he rode on the engine himself, when to his great surprise he found that there was a good deal of side play in the engine. Of course the explanation was that the engine was not a new one, and there was a certain amount of play in the axleboxes, which accumulated until it really became dangerous. Looking at the model exhibited of the axlebox described in the paper, it seemed to him that there was nothing to prevent the propagation of the same lateral motion on a piece of straight road. In working round curves he could conceive that the axlebox would adjust itself admirably; but he could not see in it any means for controlling it on the straight road.

Mr. Widmark explained that to prevent lateral oscillation there were the inclined planes upon the top of the axlebox described in the paper, which were designed to have the same effect as the india-rubber side springs that had been referred to. The inclined planes being made double, inclined both ways, resisted the movement of the engine towards either side. There was also in both cases the effect of the friction on these inclines, tending to retard lateral movement.

Mr. J. Robinson would have been glad of some information as to the application of the radial axleboxes to a coupled engine, as no doubt one of the great objects to be aimed at in any plan of

radial axlebox was to render it applicable to coupled engines, in order that the whole weight of the engine might be available for adhesion in drawing the train. A great many arrangements had been suggested from time to time for freeing the front axle so that it might place itself radially on a curve, as that was the axle which suffered most when held rigidly, in consequence of the amount of the friction, which caused great wear not only upon the flanges of the wheels but also upon the rails themselves. In the plan described in the paper, with a double inclined plane on the top of the axlebox, the engine had to be lifted in proportion to the incline each time the axle moved sideways, and therefore it always sought to come back to its central position, so that when running on a straight road there would on that account be no tendency whatever to accumulate side play. The motion of an engine fitted up in that way he believed would be quite as steady as the motion of an engine that had no play whatever. Of course there was a certain amount of play due to the actual wear on the flanges of the axleboxes; but with the axlebox now described he believed there would be just as little side motion as there would be with the ordinary fixed axlebox. In the case that had been mentioned of the "White Raven," built for the St. Helen's Railway, there were sharp curves of only 300 ft. radius round which the engine had to pass, and it was very important to get a great amount of play; and no doubt it had now become necessary, in consequence of the number of sharp curves upon the recently constructed railways, to find some way of passing round those curves which would be less straining upon the engines than where the axles were absolutely fixed and immovable as regarded their radial position to the curve of the railway. At the present time the great tendency amongst engineers was to meet that difficulty by the addition of bogies to the locomotives; and bogies had now become widely adopted in England where they scarcely existed ten or fifteen years ago. Originally regarded as an American makeshift, they had now become to a large extent adopted on English railways, especially those in the metropolis, where in consequence of the necessary curving of the lines a great freedom was required in the leading axle. But the addition of such a construction as a bogie,

weighing some $2\frac{1}{2}$ tons in excess of the necessary weight of the engine, was confessedly a very serious drawback to the maintenance of the permanent way and the economy of working; therefore he thought every effort should be made to produce radiality in the axles of locomotives on curves, either by such a plan as that described in the paper, or by such a one as Mr. Webb had described as being adopted by himself on the London and North Western Railway. Having had an opportunity of seeing the latter radial axlebox at Crewe, he was disposed to think that the whole addition made by that box to the weight of the engine was perhaps only 5 cwt., taking into account the arrangements which would be necessary for fitting up a bogie at all. The plan of checking the accumulation of lateral motion by means of india-rubber side springs appeared to him to involve more weight than the double inclined plane shown in the diagrams accompanying the paper. He thought it was true, as had been remarked, that the side movement of the axlebox allowed by that double inclined plane did tend to throw the weight of the engine very much on one end of the bearing brass; and very recently he had heard some complaints from Spain of double inclined axleboxes of this character having shown considerable danger of seizing, so that it became necessary to have these inclined planes made of steel and hardened and working upon brass boxes, in order to avoid the danger. This showed that the tendency referred to by Mr. Webb did really exist in practice. Whether his plan of getting over it by the long single axlebox extending from side to side of the engine was the right one, he was not able to say; he only mentioned that there was that objection to the other plan. There had however been a great number of engines on the Midland Railway fitted up with the double inclined planes on the axleboxes, and as far as he knew they had given great satisfaction. At any rate, what was wanted was to get rid of bogies, and to get such a radial axlebox as would admit of coupling the wheels, and thus making the whole weight of the engine available for drawing the train.

Mr. E. A. Cowper observed, with reference to the question of inclines or springs for preventing lateral oscillation, that it seemed

to him the action of the inclines was to a certain extent hindered until the friction had been overcome. Whether the two surfaces in contact were horizontal or inclined, there was a certain amount of friction between them; and until there was sufficient force to overcome that friction there would be no motion. Now with horizontal india-rubber springs it seemed to him that there was no such fixed point or fixed resistance to overcome, but the weight carried was, as it were, all alive, and was softly stopped on each side; so that without any jolt it was a soft, easy motion, and kept the engine more steadily to its course than if there were inclines to slide up and down, because with these the friction would have to be overcome before there could be any movement at all; therefore with the inclines the engine would be more likely to move with a jerk sideways than if controlled by india-rubber springs.

With regard to the unequal distribution of pressure on the axlebox and journal when the engine lurched sideways, it was not only a question whether these inclines might seize under certain circumstances, but also whether the front and back necks of the bearing might seize, because the surface in contact with the axles was not too great even when the pressure was put on perfectly fair over the whole length of the journal. If it was put on unfairly, throwing the whole pressure sometimes towards the front and sometimes towards the back end of the journals, it was likely to cause the bearings to seize, at all events if they had any tendency that way. With the single long axlebox described by Mr. Webb, or rather two axleboxes connected together by a long rigid girder, absolute truth was retained between the two boxes; the girder was no doubt stiffer than the axle, and therefore the two bearings were kept mathematically true as regarded each other.

Mr. F. W. Webb said the principle of the radial axlebox that he had described was due to Mr. W. Bridges Adams; and the method of controlling the lateral movement by means of the india-rubber side springs was similar to that used by Mr. William Adams on the four-wheeled bogie. He himself had sixteen engines on the Metropolitan Railway, fitted with Bissell bogies having double

inclined planes, and he had found so much difficulty with the inclines seizing that he had changed the whole of the radial bars and inclines of those sixteen engines, with great relief in the wear and tear, replacing them all with Mr. William Adams' four-wheeled bogie, as the engines were arranged for a four-wheeled bogie: in fact the bogie frames were worked in again.

Mr. Widmark said there were thirteen engines at work in this and other countries with the axlebox described in the paper, and no complaints had been made as to their working. As the box was so long, he thought the sliding of the pressure towards one end of the journal would not so much affect the wear of the brass or cause such unequal pressure as if the box was short. That difficulty he thought was to a great extent overcome by long boxes, and it was necessary to have a long box in this case.

The President thought the paper brought forward something which was not only of value in itself, but which would afford cause for further reflection, and particularly upon a matter that had of late engaged a great deal of attention, namely the condition of friction in the case of a tottering body. Some mention had been made of a liability of the two surfaces seizing; but he did not believe that that would occur in a case of this kind, because the tendency to seizing was never produced except when the engine was in motion, and then there was always a sufficient amount of tottering, he thought, to prevent adhesion between the two surfaces in contact. He believed however that at a future meeting a paper would be given upon that subject, and he hoped that in the meantime those who had the opportunity of thinking upon it and had experience in it and could make experiments would do so, in order to render the discussion upon so important a subject much more interesting and more conducive to valuable results.

He proposed a vote of thanks to Mr. Widmark for his paper, which was passed.

The following paper was then read:—

ON SPECIAL MECHANICAL APPLIANCES FOR MEETING THE REQUIREMENTS OF CERTAIN CLASSES OF MINE ACCIDENTS.

By Mr. CHARLES HAWKSLEY and Mr. EDWARD B. MARTEN.

In reviewing the disastrous accidents to which mines must remain liable notwithstanding every care taken to prevent them,—accidents frequently productive of great danger to the men employed and too often of deplorable loss of life, as well as involving great damage to property and not unfrequently heavy loss consequent on the stoppage of a mine during the period required for restoring it to working order,—there are two circumstances that especially present themselves to the attention, and appear to call for the consideration, of mechanical engineers.

First—The extent of the injury done, and of the danger incurred, is greatly aggravated by the insufficiency of the mechanical means available for grappling with the contingency: as for instance in the case of the sudden bursting in of a flood of water from old workings. In such an event the ordinary appliances for raising water are usually insufficient. The difficulty is a mechanical one, namely, how to bring to bear within a short time a sufficient mechanical power to raise in hours a quantity of water that would otherwise take days, when the question of life or death may be determined by the saving of a single day. It is important to bear in mind that time is the main consideration, and that every day saved in getting a mine to work again after having been stopped by an inundation generally represents a considerable sum of money which would otherwise be lost.

Second—On most occasions of mine accident many special mechanical appliances are schemed and brought into use, and frequently very useful and effective apparatus is improvised on the

site of the accident, great skill and ingenuity being displayed in its design and application; but these highly valuable appliances have not only to be devised but also constructed after the occurrence of the accident, under all the difficulties and delays incident to the imperfect means that may be within reach: and subsequently the whole are lost for future emergencies at other places, being cast aside and forgotten after the temporary object has been attained.

The object of the writers of this paper is mainly to call attention to the foregoing considerations, and to suggest means by which the difficulty may be overcome of concentrating upon any given spot a sufficient amount of mechanical power and appliances for effecting promptly and satisfactorily the work required to be performed.

To illustrate the frequency of accidents which call for the aid of appliances of the kind referred to, it may be useful here to mention the following cases from amongst many others of a similar nature which have occurred during a recent period.

At *Clay Cross*, June 11th, 1861, twenty men, three boys, and sixty-five horses were shut in by a sudden inundation, and the pumping power being only slightly in excess of the inflow of water, they could not be reached alive.

At *Steer's Meadow Colliery*, Wednesbury, February 19th, 1863, three persons lost their lives from an irruption of water at a colliery not supposed to need pumping, and where there were no appliances for meeting the contingency.

At *Botany Bay Pits*, near Manchester, November 8th, 1865, a perfectly unexpected and large influx of water burst in from the floor of the mine, overpowering the pumps.

At *Frysbottom Colliery*, Clutton, July 8th, 1867, two men were enclosed by an inundation.

At the *Nine Locks Pit*, Brierley Hill, March 17th, 1869, twelve men were rescued alive, mainly owing to the excellent working order of an unusually large engine, aided by other appliances only to be found in very large establishments.

At *Molyneux Colliery*, Mansfield, April 3rd, 1869, where four people were killed, the clearing of water after an inundation took

many weeks, although as much apparatus as possible was borrowed from neighbours.

At *Highbridge Colliery*, Pelsall, March 30th, 1871, three lives were lost because an inundation could not be subdued, so much sand coming with the water that pumps of ordinary construction were soon rendered useless.

At *Pelsall Hall*, Walsall, November 14th, 1872, nineteen men died from choke-damp before an inundation could be sufficiently subdued to rescue them, although the existing pumping plant was used with extraordinary effect.

At *Kenmure Pit*, Glasgow, February 7th, 1873, two men were supposed to have lived fourteen days in a high level after an inundation.

The accident at *Tynewydd Colliery* in the Rhondda Valley, Glamorganshire, on 11th April of the present year (1877), whereby five men lost their lives and nine others were only rescued after an imprisonment of nine days, will be fresh in the minds of the members.

There have also been numerous cases of fire, where ready means of extinguishing or controlling were not at hand, or where the quick method of flooding could not be resorted to for saving the property, owing to the inability to get the water out again except at too great a cost, as for example at the *Oaks Colliery*, Barnsley, December 12th, 1866; *Tinsley Colliery*, near Rotherham, September 15th, 1869; *Moss Pit*, Wigan, September 6th, 1871; *Blacklake Colliery*, Westbromwich, November 23rd, 1871; *Norley Hall Colliery*, Wigan, December 11th, 1872; *Titford Long-Meadow Colliery*, Oldbury, July 23rd, 1874; and in the case of the *Low Hall Colliery*, Wigan, November 15th, 1869, where, although flooding was adopted, the delay in getting the water out again caused great damage to the workings.

At *Ince Hall Colliery*, Wigan, July 18th, 1874, where fifteen persons were killed, there was the greatest difficulty in sufficiently restoring the ventilation by ordinary means to enable the bodies to be recovered; and this has also been found to be the case after many other accidents, pointing to the need of some special apparatus for the supply of air.

The need of some mechanical help for the protection of explorers after explosions is particularly shown by the recent case of the *Pemberton Collieries*, Wigan, October 11th, 1877, where thirty-three men were killed, and where three explorers subsequently lost their lives from the effects of choke-damp, when traversing the workings in the endeavour to save life; also by the still more recent case of the *Upper Blantyre Colliery*, Glasgow, October 22nd, 1877, where two hundred and thirty-three men were killed, and where considerable difficulty was experienced in entering the workings in consequence of the presence of fire-damp.

There are cases in which the employment of divers has been attempted for entering the mine or restoring the pumping machinery, indicating the usefulness of having at command specially trained divers with diving apparatus suitable for employment in mines.

It is not unusual to find that men are imprisoned by the sealing of the entrance to the mine by water, which is kept from reaching them only by compression of the imprisoned air: in which case the greatest caution has to be used lest by the letting out of the air the water should reach the men before a sufficient opening for their escape can be made. This difficulty it has been proposed to meet by the well-known air-lock; and air-compressing machinery may be used with advantage for the supply of fresh air, and even to force back the water still further from the men.

It being manifestly impossible that every mine can be furnished with the requisite spare pumping power and other appliances needful to be held in reserve for meeting the various emergencies to which the mine may be liable, it is proposed by the writers that a depôt shall be established in a central situation, from which all parts of the country can readily be reached by railway, at which there shall be kept in readiness for immediate despatch when needed, specially arranged and powerful pumping machinery and other apparatus adapted to meet the requirements most frequently arising in cases of mine accidents. An example of a provision of the kind suggested may be found in the break-down gangs with their trains of appliances, so universally and efficiently employed on railways, and kept in readiness at certain convenient centres for immediate despatch to the site of an accident.

In considering the general character of the special mechanical appliances best adapted to the purpose, the following requirements must be steadily kept in view :—

a—Ease of transport.

b—Adaptability to various situations.

c—Rapidity of erection.

d—Duplication and interchangeability of parts.

e—Non-liability to derangement.

f—Facility for repair.

The machinery and apparatus which it is most desirable to provide is principally—

1.—*Water-Raising Apparatus*, for dealing with large quantities of water in a short time.

2.—*Portable Boilers*, with fittings and steam pipes complete, for promptly and efficiently supplying with steam at a high pressure the pumping and other machinery; the boilers to be capable of being readily coupled together by interchangeable pipes, and to be prepared for transit by railway and over rough mining roads.

3.—*Air-Compressing Apparatus*, for keeping back rising water, and enabling the mine to be entered before ventilation has been restored.

4.—*Air Locks*, with provision for quickly fixing them in the headings.

5.—*Ventilating Apparatus*, for promptly restoring ventilation after an explosion.

6.—*Temporary Winding Apparatus*, for quickly replacing the winding gear over a pit when destroyed by an explosion, or for establishing an additional means of communication with the mine.

7.—*Diving Apparatus*, specially adapted for penetrating long levels under water.

8.—*Temporary Travelling Workshop*, fitted with complete sets of the tools likely to be needed.

Through the obliging assistance of several makers of the different kinds of machinery referred to, the writers are enabled to present descriptions and drawings of a few of the mechanical appliances which appear suitable for meeting the necessities of mine accidents.

It is well at the outset to note that such apparatus must not be judged by the ordinary rules of *durability* and *economy in working*, as the great objects to be attained are handiness, portability, ease in putting together, and the greatest effect in the shortest time. It has to be noted that in colliery districts the source of power—coal—is readily obtainable, and the chief point to be considered is how to extract and apply that power with the greatest rapidity and efficiency; hence it happens that classes of water-raising apparatus which are not in favour where permanent and steady work is required, may be most suitable for the purpose under consideration.

The "Pulsometer," for example, has the advantage of needing only a steam pipe and a delivery pipe; it may be lowered into water, and occupies but a small space, and when being lowered requires only the addition of extra steam and delivery pipes at the top of the shaft. Where the depth is great, several of these pumps can be placed in succession, as indicated in Fig. 1, Plate 51. The Pulsometer, of which an enlarged view is given in Figs. 4 and 5, Plate 52, is an instrument for applying the pressure of steam directly upon the water to be lifted, the only working parts being the valves A B C D, and a small ball E to direct the steam into the chambers F and G alternately. This ball is self-acting, being drawn over by the increased velocity of the steam at the moment of the formation of the vacuum. An air-vessel H, to reduce the shock, completes the apparatus.

The "Ejector," another form of instrument for raising water by the direct application of steam without the intervention of moving parts, can be used; and in Fig. 2, Plate 51, is shown an arrangement suggested for the purpose by those familiar with its use, a succession of instruments being fixed at I I. In Fig. 6, Plate 52, is shown an enlarged view of the Ejector, which operates in the same way as the well-known injector, forcing the water up the column A by the effect produced by the superior velocity of the steam jet B. It has no working parts, but is simply provided with means of adjustment. With some forms of the ejector the height of delivery is limited only by the steam pressure obtainable. In the enlarged view, Fig. 7, is

shown such an instrument; and Fig. 3, Plate 51, indicates the mode of its application when lifting to a great height.

Some of the smaller forms of direct-acting steam pumps are capable of application on emergency, as shown in Figs. 9 and 10, Plate 53, where one is suspended from the surface. The same pump is exhibited in Fig. 11, fixed in a heading to force the water to the top of the shaft, steam being supplied from the surface. Other pumps, such as that delineated in Figs. 18 to 20, Plate 57, which works either as an air or as a water pump, can also be used in a similar manner.

The Centrifugal pump is principally available where the height of the lift is small, but would be found useful where the water could be got rid of by pumping from a lower level of the mine to another level at no great height above it, as indicated in Fig. 8, Plate 53.

A form of pump which appears to be peculiarly well adapted for the purpose in view is shown in Figs. 12 to 14, Plates 54 and 55, where, instead of using wooden spears working within the pump to transmit the power of the engine, it is proposed by the designer to apply what may be termed a water spear by means of a pipe A independent of the pump B, and to connect the working parts of the pump B to a capstan engine by a wire rope C in such a manner that the rope remains attached whilst the pump B is at work, and is always in readiness to hoist the working parts to the surface, where they could be replaced by a duplicate set in a few minutes. The power is intended to be supplied from the surface by a forcing engine D, the simplest form of which is shown in Fig. 12; and all the operations could be carried on from the surface, thus enabling the pumps to be worked in any situation under water. In this way would be obviated the difficulties and delays occasioned by changing buckets and valves through door-pieces, and by drawing spears, which is often found necessary in the ordinary system of pump work, especially where dirty water has to be lifted. The mode of working may be thus described :—on the surface, near the pit, would be placed a forcing engine D capable of supplying all the power required for pumping. In cases where saving of time was of the utmost consequence, this engine might be of the form indicated in Fig. 12; but when circumstances permitted, some other form of portable engine might

be used in which advantage could be taken of expansion. A capstan engine would also be needed for lifting and lowering the pipes, and for changing the working parts of the pump as occasion required. When commencing operations the hydraulic pump B would be lowered into the pit, and pipes would be added as frequently as required both to the large delivery pump-trees E and to the hydraulic forcing pipe A. If needed, the pump might in the first instance be lowered at once to the bottom of the shaft. Where the water has to be followed as the pump is lowered, telescopic pipes at the surface could be used, of sufficient length to allow the pump to descend 30 or 40 feet without the addition of pipes. Such a pumping plant is calculated to work with but few interruptions, and the whole of the operations could be performed on the surface with facility and despatch, and without the use of steam within the pumping shaft.

In Figs. 15 to 17, Plate 56, is shown a double-acting hydraulic engine on the same principle, designed for use underground where water power is available either from the column of the main pumps or from a forcing engine. The engine is shown in a horizontal position; but for draining "dip" and distant workings it may be mounted on wheels, and made to follow the water as it is lowered, or in its most compact form it may be slung upright for use in a vertical shaft. This pump differs from that shown at D in Fig. 12 in being double instead of single-acting, and in the valves being worked by means of water pressure, in one central valve-box; and it is perhaps more suitable for use under very heavy pressures.

For the working of these and similar instruments to their best advantage, a greater pressure of steam is needed than is usually found at collieries; and as it is moreover probable that the local boilers being engaged in other work will not be available for extraordinary service, special portable boilers must be provided, those forms being selected which do the most rather than the best duty.

In Figs. 30 and 31, Plate 59, is shown a vertical boiler with internal firebox, intended to be worked at a pressure of 150 lb. per sq. in. The boiler is mounted on wheels, and is provided with trunnions to enable it to be laid horizontally when travelling by railway.

Figs. 32 and 33 represent a portable boiler on the locomotive principle, to sustain a pressure of 150 to 200 lb. per sq. in., and provided with wheels for travelling on roads. It is also capable of being carried by railway without being dismounted.

In Figs. 34 and 35 is indicated a more compact multitubular boiler.

Whatever form of boiler is adopted, it is desirable that it be made of steel plates, with the object of attaining the greatest strength with the least weight; the boilers must also be so fitted as to act separately or in groups, as shown in Fig. 36.

A portable air-compressor, with engine and boiler attached, is delineated in Fig. 25, Plate 58; and in Figs. 23 and 24 are indicated other forms of air-compressors with engines combined, but without attached boilers; whilst in Figs. 18 to 20, Plate 57, is shown a pump of peculiar form capable also of being used as an air-compressor, and an arrangement of three of these pumps combined for use where great pressure is needed is indicated in Figs. 21 and 22. Air-cylinders or other apparatus for enabling explorers to enter mines foul with choke-damp should form part of the appliances to be provided.

An air-lock is shown in Figs. 26 to 29, Plate 58. This lock is of small size to facilitate fixing, and must be securely built into the heading in which it is to be used; the materials for so doing should be kept with the apparatus, together with air-proof sheeting to be applied in the event of the dam being porous.

The boring apparatus, so ingeniously designed by Mr. Riches for use on the occasion of the Tynewydd Colliery accident and described by him in a paper read at the last meeting of the Institution (July 1877), would also be serviceable, with certain modifications to enable it to meet a variety of circumstances.

As the winding gear and pit-head frames are often injured, or are too much employed to be spared for special use, portable winding gear and engines will frequently be needed, such as those shown in Figs. 37 and 38, Plate 60; a portable frame so made as to be rapidly put together is delineated in Fig. 39.

It is essential that the whole of the apparatus should be so arranged as to be easily carried on railway trucks, a convenient form of which for the purpose is shown in Fig. 40.

Although the machinery and apparatus indicated in the drawings are for the most part doubtless well known to every mechanical engineer, illustrations have been given to make the references to them more clear.

It is necessary now to consider how the special appliances are to be provided and made available for the use of the mining community. It is not to be supposed that all that has been suggested can be accomplished without great consideration and much further information than could be obtained merely for the purpose of this paper, with respect to the special conditions of each mine, the needs of each past emergency, and the appliances that would have been best calculated to provide for them. The information so collected would lead to the designing of apparatus better adapted to the particular purposes in view than any now existing, nearly all of which has been constructed for working under other than the very exceptional conditions that obtain in the case of mine accidents.

It is hoped that these suggestions may lead to the organisation of an Association of Mine Owners for mutual protection against the calamitous results of mine accidents by the establishment of a central depôt, with perhaps a branch in each mining centre, containing a complete collection of the requisite special machinery and appliances, ready for use at a moment's notice. The cost of providing and maintaining the establishment might be met by a general subscription from those to be benefited; but the establishment should be made to a considerable extent self-supporting, by suitable charges for the use of the apparatus. In connection with these depôts, competent men should be provided for fixing and working the apparatus; a few to be permanently engaged, whilst the others pursue their ordinary work, attending at intervals for training, and being "at call" at all other times when needed.

Had such an establishment been in existence, no doubt many valuable lives might have been saved, and much pecuniary loss spared to those engaged in mining operations; and though it is not suggested that accidents of the distressing character of those that have so recently occurred could have been averted, their sad consequences

might possibly have been lessened, had appliances of the kind referred to in this paper been available. But while it falls within the province of the mechanical engineer to point out the appliances best adapted to meet the necessities of the various classes of mine accidents, it must rest with the mine owners themselves to carry the suggestions into execution.

Mr. C. Hawksley said the paper just read was not intended to be in any way exhaustive, but had been written with a view to draw the attention of mechanical engineers to the subject under consideration, and to invite discussion; and also with a view to obtain further papers from other members of the Institution, which would treat in detail the several matters that had been referred to generally in the paper now before the meeting. There were gentlemen present who had kindly furnished information respecting the pumping machinery made by them; and he hoped they would give further particulars as to the construction of the pumps which had been designed by them.

Mr. J. J. Tylor mentioned that he had ascertained from the reports of the government inspectors of mines for the South Wales district and the Manchester district the proportion that one sort of accident had borne to another, as regarded the number of deaths produced by mine accidents in those districts during the past ten years, during which the average yearly number of deaths from such accidents had been 140 in the former district and 72 in the latter. Out of the whole number of deaths thus occurring, those occasioned by explosions had been 30 per cent. in the South Wales district and 16 per cent. in the Manchester district; those occurring from falls of coal and stone 42 and 46 per cent.; those from accidents in shafts 12 and 15 per cent.; and those from miscellaneous causes 16 and 23 per cent. respectively. Deaths under the last head arose mostly from

carelessness, from the explosion of shots before the time, from men getting in the way of trams, and from other accidents of that sort. The proportion of deaths from falls of coal and stone was by far the largest in both districts; while that of deaths by drowning was very small in either district, amounting to only 0·8 per cent. in South Wales, including the inundation at the Tynewydd Colliery in the present year, and in the Manchester district only 0·5 per cent., as far as he could make out: the actual number of deaths by drowning was he believed larger in the Midland districts, though the percentage in proportion to those occurring from other causes was small.

A suggestion was offered that some provision should be made underground which might form a permanent refuge for the men. In the case of an explosion, the relief of the men was an affair not of days but of minutes; when the explosion occurred a number of men were killed on the spot near the scene of the explosion; the timber and roof was blown down for some distance, and a blast of carbonic acid gas was sent along the workings. The men first struck appeared to be paralysed, and to die instantly; but a considerable number were able to struggle for some distance, and a good many even reached the bottom of the pit. Now the force of the blast had blown out all the separation doors and brattices, and the ventilation was going through some shorter channel. The result was that, though a large number of men were left living, and might live for half-an-hour, the greater proportion of them were killed by the choke damp before assistance could reach them. The suggestion of some permanent refuge below ground, which would not cost much money, was one that he thought would meet the difficulties of the case, provided that each such refuge were supplied by an altogether separate and independent system of ventilation, which could not be interfered with by any accident. A 3 inch galvanised wrought-iron pipe would convey sufficient air to a large number of men in a series of lodge rooms. Some such plan as that might he thought be advantageously discussed. There were a great number of associations of mine owners, and any action taken in this matter as a consequence of the present discussion might very well be referred to them, as being bodies already constituted; but it was extremely difficult to

get anything done in this way. If however mine owners were agreed to establish some such system of having a central depôt, as suggested in the paper, that would meet a great many cases of mine accidents.

With regard to the question of diving apparatus, there was very great difficulty in sending men long distances with such apparatus. They could go some 200 or 300 yards; but unless a man carried a portable supply of air with him he could not penetrate a long distance underground. His firm having been engaged in perfecting a diving apparatus for depths of 200 ft., it had been found that there was some difficulty in connection with the rigidity of the dress on getting to those great depths, which gave a pressure of 10 or 15 tons on the body of a man; still it was probable that a man might live comfortably at such depths, and would be able to move about freely, and in cases where it was wanted actually to fix pumps or do other work of that sort, there would not be insuperable difficulties in the way.

Mr. A. Paget observed that in the paper which had been read it had been very properly remarked that, while it fell within the province of the mechanical engineer to point out the appliances best adapted to meet the necessities of the various classes of mine accidents, it must rest with the mine owners themselves to carry the suggestions into execution; and it had been pointed out by the last speaker that there were several associations of mine owners, to whom this matter might be referred. He was himself afraid it might be referred to them with but little effect. It was quite true that as an institution of mechanical engineers it hardly fell within their scope to initiate any action of that kind, or to take upon themselves the expense and responsibility of making the provision recommended; but he thought it did eminently fall within their scope to assist any body of mine owners who might associate themselves for any such object as that proposed in the paper, and such an object he thought was so desirable that it should be known that this Institution would be glad to give assistance by affording opportunities for the discussion of any details of machinery applicable to such purposes, or by appointing a committee to collect, collate, and give to the association any information which might be received on the subject. He had

been informed that in certain foreign countries stations of machinery as suggested in the paper did already exist.

Mr. H. Davey said that, having been brought in contact with collieries, more especially with reference to pumping appliances, he had had personal experience of two or three serious mine accidents from sudden inbursts of water. At the Garforth Colliery near Leeds, two or three years ago, a large inburst of water occurred, by the giving out of a crib which had been put in to start the tubbing upon. A special appliance had to be got ready on the spot to meet this emergency, and it was successfully dealt with by means of an apparatus constructed in the form of a hydraulic press. A hydraulic jack was mounted on a frame, with shields, one on each side of the pit, arranged to be lowered by means of the hoisting machinery down to the portion of the pit where the water had burst through the crib. The frame or cage was lowered to this point, and the shield when opposite the opening in the side of the shaft through which the water was entering was forced into position by means of the hydraulic jack, which was worked by means of a lever by a man on the top of the cage. It was not possible to get nearer to the stream of water, because it was coming in with such great force. That was an appliance which, by the ingenuity of the engineer in charge of the colliery, was very quickly got ready, and it saved the colliery. Had it failed, the colliery would have been lost, for it was impossible to deal with the water coming in through the opening by means of the permanent pumping machinery employed at the pit. That was one instance in which a colliery had been saved by a special appliance. If what had been suggested in the paper had existed in that district, probably this appliance to meet such an emergency would have been ready at hand, and could have been brought into use, and the flooding of the colliery might have been obviated; for in that case the colliery was actually flooded, and the water had risen up in the shaft almost to the point from which the stream was issuing.

Very recently too there had come under his personal observation the entire flooding of a colliery from a sudden inburst of water in the workings, through a fissure in the sandstone. It occurred

in the floor of the workings, and the water came in with such terrible pressure, and in such large quantities, that it was impossible to deal with it by means of the permanent pumping machinery. It was therefore determined to build a dam in the upper workings where the inburst occurred, and to dam back the water from flowing into the extensive workings below; whilst the dam was building, the lower workings were being flooded. In building the dam the precaution was taken of putting in a pipe with a sluice on it, so as not suddenly to dam the water up altogether; and when the dam was completed it was found there was a very heavy pressure at the back of it. In that case a special appliance, such as a hydraulic pumping engine, would have enabled the water, or a large portion of it, to be dealt with in the following manner. A hydraulic pumping engine might be worked by a large quantity of water at a low pressure, and made to lift a smaller quantity at a higher pressure, or *vice versâ*. If therefore such a hydraulic engine, capable of being worked by a large quantity and of lifting a smaller quantity, could have been put in readily in front of the dam, and connected with the pressure pipe through the dam, it would have lifted two thirds of the water to the surface; because the water that was coming through the dam evidently came almost from the surface, for it gave a pressure on the pressure gauge very nearly equal to the total depth of the shaft to the level of the dam, the water in the shaft being tubbed back. If only half the quantity of water coming in at the inburst could have been lifted to the surface by means of a hydraulic pumping engine, then the other half could have been dealt with easily enough by the permanent pumping machinery. But no such appliance was available, and the water was dammed back for some considerable time; then it burst out in another place in a larger quantity than could be dealt with, and the colliery was lost, continuing flooded to the present time.

Those were two instances in which he had been personally interested; and he had thus fully seen the importance of some special pumping appliance to deal with water in flooded collieries, and in the flooded workings of collieries; and he had been engaged for some time in scheming an apparatus which in the case of a

colliery flooded or partially flooded could be lowered right down to the bottom and put to work, and the pumping continued without interruption until all the water was got out. That apparatus was illustrated in Plates 54 and 55, and also by means of the working model exhibited. A portable pumping engine in a compact form for very considerable power was fixed at the surface, and the hydraulic pump (in the case of a flooded colliery) would be lowered from the surface, and pipes added at the top as it was being lowered, until it reached the bottom. When the pipes were completed to the bottom, it was only necessary to connect the smaller pipe to the pumping engine, and the motion of the engine caused a corresponding motion in the working part of the pump at the bottom of the pit. That working part of the pump remained attached by means of a wire rope to a capstan engine on the surface, either the ordinary capstan engine of the mine or a portable capstan engine supplied with the apparatus. Should the working part fail, either from ordinary wear and tear or from any accident, it was only necessary to throw the capstan into gear, and hoist the working part to the surface. A duplicate would be kept in reserve, to be lowered down when wanted. The capstan would then be thrown out of gear, and the apparatus would be ready for working again. The engine was a simple steam cylinder, working either a pair of vertical plungers or only a single horizontal plunger, and from it the small pipe passed down the pit to the hydraulic pump at bottom, so that the water which was confined in the pipe between the engine plunger on the surface and the pump bucket at the bottom formed a water spear, as it were, between the engine and the pump; and thus the pumping action of the engine on the surface produced the same motion in the pump below, whereby the water was raised.

Mr. T. Hurry Riches observed that with the hydraulic engine which had been described it appeared to him there would be a large quantity of water sent down the pit, or extracted from the main column of the pumps, and used towards pumping up virtually half the quantity, or at any rate the amount raised would be less than that expended in consequence of the friction having to be deducted

from it; and he could not see the advantage of the hydraulic engine if used in the main shaft. It would be useful he thought for raising from the lower levels to the upper, where the main pumping engine could raise only a limited quantity from the lower workings while there was ample pumping power from the upper levels.

The air-lock shown in the drawing seemed to him to be rather short; and he enquired what length was proposed for it. The death rate from drowning which had been mentioned appeared to him to be very small, and he thought it hardly could have included the case of men who were imprisoned by water, as in the recent Tynewydd inundation, where, had the rescue not been successfully accomplished, the deaths would have been attributable to drowning, although the men were simply imprisoned by the water. With regard to the proposal of carrying down a galvanised pipe to a place of refuge in the workings, for the purpose of conveying away foul air, or of supplying fresh air to the men entombed by an accident, it appeared to him questionable whether that would be advisable or not. Under similar circumstances to those at Tynewydd of the water entombing the men, if the air were not confined in the place of refuge a very vital element of the air-lock would be destroyed, and the water would be allowed to rise and drown the men; and thus an air supply pipe would be worse than useless, unless an efficient air-lock were also maintained.

Mr. R. Price Williams remarked that, having long been directly connected with coal mining and deeply interested in such operations in South Wales, he could not but think so practical and admirable a suggestion as that embodied in the paper, of the formation of what on railways were known as "break-down gangs," for concentrating in the shortest possible time all the improved appliances for rescuing the lives of entombed miners, would command at once the consideration of all coal owners, as he was sure it would of all the owners whom he knew in the district with which he was connected. He was only surprised that such a suggestion as that now made had not been adopted long ago. From his own personal experience he could state that, had such ready means been available

in the collieries in which he was interested, the lives of a great number of men might have been saved; he could recall one instance where, if any such appliances had been ready to reach the men before they were overcome with the after-damp, the lives of many would have been saved. Unfortunately in that case, as generally happened in explosions, all the gearing was blown away by the force of the explosion, and a long interval elapsed before it was possible to get to the men; and when at length they were reached, though warm and possibly still living, the overpowering effect of the after-damp upon the explorers was such that the men whom they reached had to be abandoned. He had been struck with the suggestion of having certain appliances for supplying compressed air; but it appeared to him that one help not indicated in the paper might yet be provided, namely some means of supplying fresh air by such an apparatus for instance as was used by divers. That would have enabled the rescuers, who in the case he had mentioned nearly lost their lives in their unsuccessful attempt, to have succeeded in recovering the men. Reference had been made in the paper to the importance of the saving of a day in getting a mine to work again after an accident; but most of the accidents from explosions in collieries turned not upon the question of hours but minutes; and he suggested that, besides having an organisation such as had been indicated, it would be well that at every colliery appliances should be ready such as were referred to in the paper for supplying compressed air, so that, without waiting for the break-down gangs to come, these appliances should be in readiness, in order that they might at once be got down into the pit. One of the greatest dangers in collieries as mining grew older was that of sudden inbursts of water; in the South Wales district the old workings extended for miles, and the inundation at Tynewydd Colliery was the result of an inburst of large masses of water from the old workings in an adjacent colliery. This made it all the more necessary that an organisation of the kind suggested should at once be set on foot; and while he agreed that it was not within the province of the Institution to initiate such an organisation, the interests at stake were so important that he thought it would be well, if colliery owners were supine in the matter, that pressure

should be brought to bear upon the Board of Trade or upon the Government, in order that organisations similar to the railway break-down gangs should be formed in every mining district, and that the coal owners should be required to contribute to their support and maintenance. He did not think it would require compulsion; but that, directly this matter was brought, as he hoped it would be brought, prominently before the coal owners, they would take it up, and that there would be established in this country such practical organisations as he was glad to understand were already on foot and acting efficiently in Belgium and elsewhere. A very ingenious contrivance for rapidly getting rid of bad air, which he thought might usefully supplement the plans referred to in the paper, had come under his observation recently on a visit to the coal mines in the North of England, where at one of Mr. I. Lowthian Bell's pits an ejection of steam was employed at the bottom of the upcast shaft for improving the ventilation; he understood from Mr. Bell that it was remarkably effective in accomplishing that object, and it struck him that the appliance there used might be very readily adopted in the case of an explosion, to exhaust the bad air rapidly by the ejection of steam in the upcast shaft. He was also particularly struck with the ingenuity and readiness of application to an emergency of this kind, of what had been termed the water spear; it seemed to him admirably adapted for such an occasion, and as affording the means of getting pumping apparatus down the pit and dealing with the water in a manner free from complication. He should be glad to know the quantities of water that each of the several pumping machines referred to in the paper was capable of delivering in a certain time. In the Tynewydd and other colliery inundations it was a question of the quantity of water to be pumped up in the least possible time in order to get at the men; and if some definite statistical information could be obtained from the makers of these machines as to the quantities of water that could be delivered in a given time, it would be very useful to the colliery owners. In regard to a place of refuge for the men underground, he could not help thinking there was a danger in such a plan; in explosions particularly, everything was blown away, and his fear

was that such a place of refuge might then become a trap; for if there were not absolute certainty of maintaining by means of a conduit both ingress and egress of air to the refuge, it would only be a short way of ending their lives for the men to take refuge there. The men themselves he knew had a notion that the best thing to do was to make their way as rapidly as they could to the bottom of the shaft; and such refuges as had been referred to, unless it was certain that the means of communication with the outer air could be maintained, would be attended with a very serious risk.

Mr. J. C. Fell thought there was surely a fallacy in the proposition made with regard to the use of a hydraulic engine to relieve the accumulation of water in a flooded mine. In the case instanced by Mr. Davey, he understood that the water had been dammed back, and a head of water accumulated to a considerable pressure; and that the proposal was that this head of water should be utilised to free itself through the means of a hydraulic engine, supplemented by an ordinary pumping engine. Now the head of water accumulating behind the dam was obtained only by the damming back of the water; the head did not exist till the dam was introduced, the inflow of the water being gradual. If then, after the pressure had accumulated behind the dam, this pressure was used through the hydraulic engine to deliver a portion of the water dammed back, the moment any quantity of water was withdrawn through the dam in excess of that coming in behind it the head of water would cease to exist to the full height; the hydraulic engine would then cease to act, and ordinary pumps would have to be depended upon as before. In fact, as far as he could see, no hydraulic engine could deliver the water from behind the dam at all; for the water taken off to work the engine would relieve the pressure of the head of water behind the dam, and as soon as ever that head was relieved the hydraulic engine would cease to act, and ordinary engines would once more have to be depended upon.

Mr. E. A. Cowper considered the suggestions made in the paper were certainly admirable and well directed; but he thought what was required in order to induce colliery proprietors to stir at all was

that some extraordinarily good appliances should be shown them—something that would at once commend itself to them as being useful and worth laying out money to procure. Unless some implements were put before them, that would induce them to lay out money, they would not do it, simply at the suggestion of engineers. Some of the best schemes extemporised on the spot at the time of colliery accidents were often not only forgotten, but not known at all in other collieries; the plan was just known in the one colliery where the accident had happened, but the knowledge of it was not spread to other collieries; consequently it had to be all invented afresh, or perhaps was not invented at all, when it was required again on some subsequent occasion. If the knowledge of these appliances were spread to other collieries, and especially if the apparatus itself were kept as suggested in the paper, good might be done in the case of a second similar accident. It fell within the scope of the Institution he thought to suggest any such machinery that the members might know of, but it was not within their scope to start an association of colliery proprietors; it must be left to the colliery owners themselves to organise such a body.

It seemed to him that one of the first things wanting was ventilation. If it were wished that explorers should go down and see what was the cause of an accident, and get the men out if possible, air must be carried with them. A very simple plan had been used to his knowledge in some collieries; with a 10-inch pipe made of tin or sheet iron or steel, and a small blowing fan at the surface, ventilation had been carried 800 yards along a small heading, and in another instance as much as 1,100 yards; it required but little pressure, the pipe took up but little room, and the ventilation was most efficient. The suggestion of having a powerful steam ejector in the shaft was also an excellent one, and it might be applied on the spur of the moment by lowering a steam pipe say 50 feet down the upcast shaft, which would have a valuable effect in assisting to exhaust the shaft, but would not produce any considerable degree of vacuum. But he believed the most necessary instrument was a powerful pump: in the case of a colliery which was being drowned from the influx of water, some sort of pump was wanted that could be lowered from the top of the pit so as to exhaust the water quickly. The suggestion of

Mr. Davey's pumping arrangement with the water spear seemed to be something in that direction; it was a very ingenious and admirable suggestion, but he could not help thinking that something a little simpler would be still better. It struck him that it might be possible to have a single pipe, part of which should serve as the pump barrel, according to an old well-known arrangement where there were two buckets working in the same barrel, one bucket below the other, working contrary strokes, and each acting as a valve to the other, so that there was a constant column of water coming up continuously. He did not say that that would be a good form of pump for long-continued working, but for an extempore job he thought something of the sort might be adopted:—a simple pipe say 12 in. diameter, made of thin sheet steel, with joints of india-rubber, put together quickly, and lowered straight down, with two pump-rods working one within the other, fetching the water up to the top, without requiring any fixing to the sides of the shaft, and not subject to any swinging about, because the power would be entirely contained within the pipe itself and the strain would be entirely on the buckets. With a powerful engine, perfectly portable, that could be brought up close to the pit mouth (letting the tackle overhang), he thought this plan of pumping might be found to be useful for clearing out a pit when it was drowned.

Mr. R. H. Tweddell enquired the weight of the hydraulic pumping apparatus shown in the drawing, and whether this rendered it difficult to handle when the bottom pipe was at any considerable depth below the surface; for, as he understood the arrangement, the pipes would have to be continually lowered as the water was gained upon in the pit. It seemed to him that this system involved as much trouble as the ordinary system of spears. He did not clearly see the advantage of the application of the hydraulic pumping engine, and he rather agreed with the remarks of a previous speaker; but in his opinion the conditions of the case were exceptional. In reference to the statement that so many good contrivances were invented at different collieries, but that the knowledge of them was not wider spread, he thought this difficulty

would soon be overcome, as these subjects were now being rapidly brought by mining engineers before bodies connected with their own profession, in the North of England and also in Wales. With regard to improvements connected with the saving of life after accidents in mines, a paper conveying somewhat similar ideas had been read before a society at Cardiff by Mr. Upward, whose air-lock was well known and had been referred to at the last meeting. This ingenious arrangement for conveying food and helping to extricate men from mines appeared to him likely to prove thoroughly efficient; and seeing that a similar but temporary arrangement devised by Mr. Riches at the Tynewydd Colliery under very trying circumstances had proved satisfactory, it was unfortunate that Mr. Upward's apparatus was not used on that occasion. Several suggestions had already been made as to who should carry out the organisation recommended in the paper; and he quite agreed that this Institution was in a position to offer suggestions as to the best way of carrying out the mechanical details; but no one had remarked that the question should be one as he considered quite as much for the miners themselves. If they and their advisers were to combine for the purpose of saving their own lives and their masters' property with the same vigour that they already combined for restricting the output of the coal, it would be a national advantage. He also thought that, as had been suggested in the paper read at Cardiff to which he had referred, it would be a good plan to institute some reward of merit to induce them to work as the lifeboat men and the fire-brigade men did, and to distinguish themselves by saving life; it might possibly encourage skill and promote improvements in the ways and means of saving life under such difficult circumstances. He did not mean by this that such a material incentive was necessary; there was indeed no occasion to look further than the recent catastrophe at Wigan, to prove that no such incentive was necessary when the lives of their fellow-workers were in danger.

Mr. J. Robinson observed, with regard to the use of the ejector for drawing water out of a flooded mine, that no doubt the ejector shown in the drawing would be a very effective

though a very expensive means of lifting water out of a mine, or of raising water for any other purpose; though it had been stated that it was not a question of expense, nor indeed could it be so, under the circumstances which were presented by mine accidents. But there was another advantage that the ejector possessed, namely that the same or nearly the same instrument he believed might be used for extracting air as well as water, so that a current of foul air or choke-damp might be drawn up by the ejector actuated by steam exactly in the same way as when drawing up water. A little consideration in that direction would probably cause a diminution in the number of appliances requisite to be provided, because in this instance one appliance might be used both for water and for air.

Mr. E. A. Cowper said he had not meant to suggest that the same ejector would do for water and for air, because the areas and spaces were so very different; the raising of either water or air by the ejector might be done on the same principle, but he did not think by the same instrument. Ejectors for ejecting air in very large quantities had been made by Messrs. Körting, and were very efficient; and if several large steam jets of that kind were put down 20 or 30 ft. in a pit shaft, the whole area of the shaft might be made to serve as a pipe for ejecting air from the pit.

Mr. H. Davey mentioned, in reference to the suggestion he had made for working a hydraulic engine under the special conditions which he had described, that there were in that instance 1,000 gallons of water per minute flowing into the mine under a pressure of 700 ft. head, and the total depth of the mine was 1,000 ft. To send the whole of the 1,000 gallons to the bottom of the mine for the main pumps to deal with would have been impracticable, because the main pumps were not powerful enough for that purpose; but if the quantity could be reduced from 1,000 to 500 gallons, then the pumps could deal with it. Now it was obvious that 1,000 gallons of water flowing under a pressure of 700 ft. head was pretty nearly if not quite enough to lift 500 gallons 1,000 ft. It was quite necessary to send the whole

of the 1,000 gallons of water to the bottom of the mine, to get to the pumping machinery; that was a condition which very often occurred in the drainage of mines. In falling the 300 ft. from the upper level to the bottom, the water would be doing no work; but by passing it through a hydraulic engine the force of that fall added to the pressure existing at the upper level might have been utilised to raise a portion of the same water to the surface. At the Ouston Colliery near Newcastle he had carried out a similar arrangement. A large portion of the water, 500 gallons per minute, was met with in the upper workings where there were no means of dealing with it; and it was necessary that that water should be sent to the bottom in order that it might get to that portion of the mine where the pumping machinery was situated. He had put down a hydraulic engine at the pumping station and simply piped the water from its source, so that the water drained from the upper workings raised a portion of itself to the surface, and relieved the pumping machinery of some 200 gallons per minute. Although 500 gallons still went to the bottom of the mine, yet in going down it pumped up 200 gallons of itself to the surface, so that the balance or 300 gallons per minute was all that had to be dealt with by the main pumping machinery.

The President asked why the 500 gallons were not brought up at once from the higher level, without being sent down to the bottom of the mine.

Mr. H. Davey replied that the circumstances of the case would not admit of that being done; there were no pumping appliances at the upper level, nor would it have been possible to provide them there without incurring very heavy expenses, which would not have been advisable under the circumstances. With reference to the weight of the water-spear pump, for meeting emergencies it would of course be made as light as possible, probably of sheet steel, thereby reducing its weight to perhaps one-third of the weight of ordinary pumps. The details, such as the jointing of the pipes and so on, would require of course very careful consideration.

Mr. T. Hurry Riches suggested that, in a case such as had been referred to, where it was possible to control an inburst of water into a mine by merely erecting a dam across for damming the water out, the easier way would be to have in the shaft an uptake or rising pipe connected to the dam, and let the water rise in this pipe until it found its level, and then pump it to the surface from that point. It seemed to him rather a roundabout way to let the water run down to the bottom of the mine, and then pump it up afterwards.

Mr. Jeremiah Head thought the objects recommended in the paper might be summarised as the keeping in warehouses in certain colliery districts of a certain number of appliances which could be utilised in case of need. One of the great difficulties was that these appliances cost a good deal of money, which must be found by some one, and the interest of which must eventually come to be a charge upon the cost of coal. Now the profit on coal at the present time was stated by the colliery owners to be very bare indeed, and probably they would raise that objection to the plan suggested; but makers of appliances such as these were very easily prevailed upon to send specimens of their goods to international and other exhibitions, and the cost of doing so appeared to be worth their while to incur, owing to the notoriety which their different inventions got. He therefore suggested that if colliery owners would only go to the extent of providing in their several districts suitable warehouses, and would then send round notices to all the makers of these kinds of apparatus, stating that the warehouse would be at their disposal for holding a specimen or two of each of their machines, it was possible that the makers of such machines would find it to their interest to put one or more of their machines in the warehouses, not only to make them better known, but also because there would be a good probability of their being taken out at some time or other at a very fair price in cases of emergency. It occurred to him that perhaps a combination of the makers of machines for providing the capital necessary for the machinery, and of the colliery owners for starting the idea and finding warehouses, might facilitate the accomplishment of the object contemplated.

Mr. W. Richardson thought the paper was a very suggestive one for a mining district like Lancashire, where it was so important to have in readiness some means of dealing with mine accidents when they happened. Having himself once been concerned with a drowned mine, he knew what anxieties and difficulties were connected with them; and the idea of Mr. Davey's water-spear pump, as far as he could see, appeared about as good as anything that could be adopted. In these matters it struck him there was a commercial as well as a mechanical aspect to be considered. At Woolwich Arsenal cylinders were now being made of fluid-compressed steel by Sir Joseph Whitworth's process, capable of bearing 1,000 lb. pressure per sq. in., in order to construct torpedoes very light, so that they would carry shot and gun-cotton enough to destroy a ship; and he suggested that the same process might be applied to the manufacture of very light pipes for standing the heavy pressures to which they would be subjected when lowered into deep mines—pressures as heavy as were already dealt with by Sir William Armstrong for dock works on the surface; so that these light tubes might be conveniently raised and lowered for working hydraulic engines in the bottom of the mines to force the water up. The work to be done was no child's play: at the bottom of a mine 300 yards deep the pressures to be dealt with were so great that neither ejectors nor any other such appliances would do: some appliance was wanted that had really got great force and strength about it. The water-spear pump he thought was an admirable scheme, very well adapted to the purpose desired; and it suggested the use of steel tubes made as light as possible to bear the great pressure, so that they could be lowered as proposed from the capstan engine of the pit or from the regular winding engine, into the position in which they were required for working. Such a pump would work when entirely submerged under water, as well as on the surface; there was no condensation taking place, and therefore no force being lost, and there was no steam being discharged into the shaft to interfere with the men working there. The object was to reduce the weight to a minimum, so that it could be conveniently dealt with, because in these cases the weight of pipes to be dealt with amounted to hundreds of tons. He did not mean to say that the

thin steel pipes would do permanently, for in many collieries bad water was met with, which destroyed the metal very soon; but for emergencies they would last long enough till the inburst of water was pumped out of a flooded colliery. In some of the early collieries of the Lancashire district a difficulty arose from their having been opened with too little capital, and the shafts having consequently been built very small and very badly, so that when they got flooded with water the clay or earth or other material behind the lining of the shafts began to swell, the shafts collapsed, and the colliery was often lost. The loss of a colliery in a neighbourhood seemed to him to be as bad as the loss of a factory. The authorities of a town provided steam fire-engines and other apparatus to put out fires, for fear of the destruction of property, and the people were taxed for providing the means of putting fires out. Now it was as great a misfortune he thought to a community or neighbourhood to lose a colliery as it was to lose a factory, because the coal could not then be got in the neighbourhood, and had to be got somewhere else, and the railway rates had to be paid. If the appliances suggested in the paper were kept in a district by taxing those for whose benefit they were to be employed, he thought the commercial aspect of the case might be met as well as the mechanical aspect.

Mr. J. Sturgeon thought there should be no difficulty in getting up an association such as had been suggested in the paper, after the style of the Liverpool Salvage Association or the Under-Writers' Association, which were very valuable and did a great deal of service. The matter of economy in steam was he thought more important than seemed to be imagined in the paper; the use of ejectors or other apparatus involving the expense of a continual flow of steam to get the water out of mines might require additional boiler power. Attempting to save weight of material by the employment of steel plates for boilers, while at the same time using apparatus that required more steam and involved the necessity of extra boilers, was not, as it seemed to him, the most direct way of going about the work. A little attention to the matter of economy in the first instance he thought might save a great deal of trouble afterwards.

With regard to the air-lock, in many mines there was compressed air laid on, and in such cases it would be an easy matter to make a connection through the air-lock, under circumstances like those shown in Fig. 8, Plate 53; and by forcing the compressed air into the lower workings of a flooded mine the water might be driven out into the upper workings, provided the head was not so great as to necessitate too great a pressure of air for the men to stand; while at the same time air would be supplied to keep the water away from the men in the lower workings.

Another point which had been just touched upon in the paper was the desirability of providing some means of protection for explorers who had to descend into mines after an accident. He thought that something in the nature of a helmet supplied with air, just to pull over the head, would enable them to exist a longer time in the foul air, and perhaps to stay there altogether until the exploring work was completed. Again it would be an advantage if the explorers were attached to one another by means of ropes, in the same manner as Alpine adventurers, so that in case of one or two being overpowered the others might assist in drawing them out.

Mr. J. F. Seddon wished to express his approval of the general features of the paper which had been read, having himself some knowledge of most of the appliances referred to; but he thought thanks were due to the authors for having brought before this Institution the various inventions alluded to in the paper. With regard to the carrying out of the suggestion that those engaged in mining should co-operate for the purpose of having these appliances ready in case of accidents, he had no doubt that, when the subject was duly brought before those who were most interested in it, it would receive very careful consideration. It was not the wish, intention, or practice, he was sure, of those who owned or managed collieries or had the charge of workmen in mines, to spare any expense where the men's lives were at stake; and considering the remarks which had lately been made in public upon this matter, it could not be too freely made known and believed that the body of mining managers and colliery proprietors throughout the country were at all events as careful of the lives of their men as any other class of employers of labour.

Mr. C. Hawksley, in replying upon the discussion, observed it had been mentioned that divers could proceed only some 200 or 300 yards distance in a mine; but with special appliances, such as would result from the consideration of the work to be done in cases where colliery workings were submerged, it was believed they might be enabled to proceed much further; as for instance if the air pipes were made so as to float, or nearly to float, thus decreasing the weight which the diver had to drag after him. The reason why the divers did not reach the imprisoned men in the Tynewydd Colliery he believed was that the length of the air pipe became so great that they could not drag it after them, although one diver proceeded to only half the distance to which the other man went, and paid out the pipe to his comrade in front.

With regard to the suggestion of providing underground refuges, he thought these would be very good if properly carried out, and might in some cases result in the saving of life, both in the event of inbursts of water and in the case of explosions, if the men could reach them before being suffocated by the after-damp.

As to the length of the air-lock, it ought not to be made less than 6 ft.—perhaps 7 ft. would be better; but it should be long enough to enable a man to lie in the lock with ease when both doors were closed, otherwise it would be impossible to close the outer door before opening the inner one.

In reference to the suggestion that possibly government interference might be brought to bear on owners of collieries, for his own part he should be sorry to see government action called for with a view to hamper colliery owners more than was already the case; and he thought any organisation of the kind which had been proposed should be carried out voluntarily by the colliery owners themselves, who would then be likely to do it much better than if it were forced upon them by any legislative action.

Respecting the use of the steam jet for ventilation, he had recently been informed that a pit in the neighbourhood of Manchester was now being ventilated temporarily by steam jets lowered into the upcast shaft, and that the system worked very well.

With regard to the quantity of water to be raised by the different kinds of machinery referred to in the paper, that was a matter which, should the proposal be carried into effect, would have to be determined after consideration of the depths of the mines in which the apparatus might have to be used and of the quantities of water which would most probably have to be dealt with; but he believed it would be quite practicable to transport from a central depôt appliances which would be capable of raising 1,500 or 2,000 gallons per minute to a height of 200 yards.

Referring to the objection that a hydraulic pumping engine could not work with a gradually diminishing head of water, the case supposed by Mr. Davey was one where the head was constant, and where the water could not be lifted from the point at which it entered the mine, owing either to some peculiarity in the workings or to some other cause which had not been explained, and where consequently the water must be allowed to fall to the bottom of the pit and there be raised by steam power by the ordinary pumps if advantage were not taken of the head from which it came in order to raise a portion of it by hydraulic power.

In the suggestion that it would be very desirable that the Institution should recommend to mine owners forms of apparatus best calculated to deal with mine accidents, both Mr. Marten and himself entirely concurred; and hoped the present paper might be the pioneer of others on the same subject from the makers of various classes of machinery, who would be able to bring before the Institution apparatus in the forms best suited to the particular objects in view. Much also might be done if colliery owners were to take the matter up, and were to appoint some person on their behalf to look thoroughly into the question, and to collect data as to the heights to which water would have to be lifted, the quantities to be dealt with, and other particulars, which might be tabulated and laid before the Institution in such a form as would enable the members to design machinery that would be capable of dealing with the various circumstances most likely to arise; upon these and other points much more information was needed than could be arrived at by any individual for the purposes of a paper of the kind now under discussion.

With respect to the suggestion that a blowing fan should form part of the apparatus provided for mine accidents, he thought there were various kinds of fans that would be suitable for the purpose; and not only fans, but other blowing apparatus, such as that illustrated in Figs. 18 to 20, Plate 57, together with Roots' blowers and other well-known ventilating machines.

Adverting to the weight of the pumps to be employed for raising the water out of a flooded mine, it was intended that all the apparatus should be made as light as possible; and with that view steel would be largely employed, not only in the pumps but in the machinery generally.

The proposition that makers should be asked to contribute apparatus at their own expense would no doubt work well, if the appliances in ordinary use were suitable for the particular purpose in view; but that was hardly the case, he thought, inasmuch as they would for the most part have to be specially designed. For instance, they would have to be made exceedingly light, and be capable of being put together with great facility, although perhaps not in such a way as would be best adapted for permanent fixtures. Therefore the machinery contributed would really have to be special machinery, and must he thought be paid for by those who received the benefit from its use. It was intended to keep this apparatus loaded on trains at the central depôts, so that, in the event of an accident happening, a train laden with suitable apparatus might on the receipt of a telegram be sent off within a few hours to the scene of the accident.

Respecting the suggestion that town councils might provide the apparatus required for the purposes contemplated, he thought this was hardly a case in which they could be called upon to act. It was true fire-engines were provided in that way; but then the object of providing fire-engines, he considered, was not so much to protect the property of the individual whose house was on fire, as to protect the property of the inhabitants around it: and therefore it became a public duty, which would not be the case with respect to mine accidents. Mention had also been made of the Salvage Association established at Liverpool, by which a steamer was kept fitted with diving and other apparatus and everything in readiness for immediate

despatch to a wreck, with the object of recovering the ship or such property as might be saved from it. That was a very good illustration, he thought, of what was proposed to be done for collieries.

With regard to the economy of steam, it would be necessary, in designing the requisite apparatus, to take into consideration all the circumstances that would arise, and to balance them carefully, in order to arrive at the particular class of machinery which would consume the least steam compatible with the other objects in view, namely the weight of material to be carried, the rapidity of erection, and the possibility of getting the apparatus into the pits and other places where it would have to be used.

With respect to the protection of explorers, referred to by Mr. Sturgeon, it was the intention of the writers of the paper that apparatus for that purpose should be kept at every pit: for instance, an appliance somewhat like a diving dress, but only covering the head and shoulders and the upper part of the body and supplied with air from pumps. Such apparatus had already been constructed by Messrs. Siebe and Gorman, the helmets being made very light, of wicker-work covered with india-rubber or some other light air-proof substance. Air was supplied to the helmet through a flexible tube from pumps at the top of the shaft. That apparatus, which would not be very expensive, might be kept at every colliery, so that immediately after an explosion it would be in readiness to protect the lives of the explorers. He would suggest that these appliances should be kept under the supervision of the officers of the central establishment, by whom they should be inspected from time to time: further, the viewers, overlookers, and other men engaged in the colliery, should be specially trained to the use of the apparatus, and also to the use of the diving dress for working under water, which might be done without difficulty; and if they were so trained and exercised in it at intervals, say yearly, they would then, from their knowledge of the workings, be enabled to work underground to much greater advantage than any divers brought from a distance and unacquainted with the pit which they had to enter.

The present paper had been brought forward because it was thought, however desirous colliery managers might be to ensure the safety of their men, it was utterly impossible for each colliery to be provided with all the apparatus which ought to be accessible in the event of an accident. It would be no more possible for each colliery proprietor to provide all this apparatus than it would be for each householder to maintain his own fire brigade.

He desired to express the thanks of Mr. Marten and himself to the many gentlemen who had aided them by descriptions of their apparatus and by the suggestions they had made; also to many colliery managers and proprietors and others interested in the working of mines, who had been so good as to communicate their views and to express their interest in this matter; and to Mr. Marshall for the great aid received at his hands in the preparation of the paper, and for the interest that he had taken in it.

The President thought this was a very important subject, and it was worthy of consideration also from another point of view than that which had been indicated in the paper. There were a vast number of cases connected with sinking and mining operations, where apparatus of that kind, supplemented perhaps under particular circumstances by other apparatus, was wanted for urgent but very temporary purposes. There was, for instance, a case of his own, which ended very unfortunately, and which was only a few months old. At the bottom of a pilot shaft he was sinking for water, which was intended afterwards to be deepened, a bore-hole was put down to the water-bearing strata, and water rushed out in very large quantities. The hole was plugged, and, it was thought, plugged with success. However, some time after that operation, the water began to come out in large quantities sufficient to beat the pumping apparatus. As a large permanent shaft was being sunk in the immediate neighbourhood, it became necessary to get the water out of this pilot shaft; the effort was made, and failed. Had such an apparatus as was indicated in the paper been accessible, it could have been sent for to take the water out, so as to enable the sinkers to get to the plug, withdraw it, insert another plug, and then go on with the

other operations. That perhaps might not have taken more time than a day or two; and a very large sum of money, as well as a life which was unfortunately lost in the operation actually attempted, would have been saved. In consequence of not being able to get to the plug, and the water rising and rapidly attaining a great height in the shaft, divers were resorted to, and some very good and experienced men he believed were obtained, one of whom went down more than once; but on the third or fourth occasion he had been down but a very short time when he ceased to signal; he could not be got up, and his life was lost. Now if there had been such apparatus as that described in the paper, it would not have been necessary to send the diver down, and that life would not have been sacrificed. But, besides that, although other divers were sent down and did re-plug the hole, they had not plugged it soundly, the water being of great depth in the shaft and the difficulties being many; and at the present moment, in consequence of the leakage of the plug, a very large part of the difficulty was still being suffered which had occasioned that loss of life. There were a great number of other circumstances where special apparatus would be of great value. Suppose, for instance, a pump went wrong, and it was wanted to get to the clack door or to the bucket door, and it was important that the operation should be effected in a very short time: by sending for a special pumping apparatus of that kind the shaft could be emptied and the proper remedy immediately applied. There were thousands of instances constantly occurring in which a resort to an apparatus of that kind, other than for the purpose indicated in the paper, would be useful. He believed that it was quite possible to get an association of mine owners and others to establish a central depot: it need not be a very ponderous matter, and need not involve such a sum of money as mine owners would not be easily able to raise.

He proposed a vote of thanks to Mr. Charles Hawksley and Mr. Marten for their paper, which was passed.

The following paper was then read:—

ON AN IMPROVED CONSTRUCTION OF HYDRAULIC PRESSES FOR PACKING COTTON, JUTE, &c., WITH IMPROVED ENGINES AND PUMPS.

By Mr. ROBERT WILSON, of Patricroft.

The object of this paper is to point out the advantages of working Presses and other Hydraulic Machinery at a high speed; this at one time was considered impracticable, but the writer's experience of the packing of cotton and other fibre in India shows that it is not only practicable but can be carried out with great advantage. Until late years hydraulic power was used only for very slow direct action; and in packing presses for goods, the motion was so slow as hardly to be perceptible to the eye, requiring 10 to 12 minutes to raise the ram of the press $3\frac{1}{2}$ to $4\frac{1}{2}$ ft., which can now be accomplished in less than half a minute. When the writer proposed to apply direct-acting hydraulic power to the presses used for packing cotton in India, it was considered quite unsuitable for presses with a rise of ram of 12 ft., as it was generally thought that this rise could not be obtained in less than 15 to 20 minutes, which would only allow of three bales at most being turned out per hour, giving no advantage over the hand-presses at that time generally used in the cotton districts in India. So little confidence was placed in the writer's plan for accomplishing this amount of rise of ram in one minute, that it was with difficulty a firm of merchants in Bombay were at length induced to make a trial of a cotton press on this principle, a guarantee being required by them that the ram should be run up a height of 12 ft. in not more than 5 to 6 minutes, which, if performed, would turn out eight bales per hour.

The Press, which is illustrated by the model exhibited, was made and sent out to India in 1857. Its weight is about 30 tons, and it is fitted with two 11-inch rams, and a cotton box $13\frac{1}{2}$ ft. long by

16 in. broad, having a rise of ram of 12 ft., and capable of compressing $3\frac{1}{2}$ cwt. of cotton into 8 cub. ft. in the press, with a pressure of 500 tons upon the bale. The report received of the working of this press was most satisfactory, stating that twelve bales could be turned out per hour, and that the press could be run up in little more than one minute. This result was obtained through the medium of the horizontal direct-acting high and low-pressure pumping engines invented by the writer, which are shown in Figs. 1 to 4, Plates 61 and 62. The high and low-pressure engines were constructed in pairs from the same design, with cylinders 20 in. diameter and 24 in. stroke, each pair working four direct-acting pumps, the low-pressure engines pumping water up to a pressure of 1,680 lb. or $\frac{3}{4}$ ton per sq. in., and the high-pressure ones up to a pressure of 3 tons per sq. in.; this difference was brought about by making the pump rams of the low-pressure engines four times the area of those of the high-pressure. The mode of working was as follows:—in starting the press, the resistance of the cotton being then slight, both high and low-pressure engines were set to work, so as to run up the press as quickly as possible; when the resistance of the cotton counterbalanced the low-pressure engines, these stopped of their own accord, and the high-pressure engines finished the bale.

Upon the result of the first press being ascertained, five more presses were ordered to complete a set that would keep the two pairs of engines continually at work, and so obtain the full advantage of the engine power. The proprietors of hand-power presses, seeing how rapidly they would be pushed out of the packing trade, put forward numerous objections to these powerful competitors; amongst others that the great pressure exerted to compress the bale destroyed the fibre of the cotton. On the arrival of the cotton at Liverpool this matter was carefully gone into, and all objections vanished after the first season; and the screw presses were speedily abandoned for the new hydraulic ones.

So far a great success had been achieved, but not sufficient to satisfy the writer; and in 1862 he designed the three-cylinder press shown in Fig. 5, Plate 63, fitting it with three 9-inch rams, and making it of similar size and power to the first hydraulic presses.

The object of this second plan was to obtain with only one pair of engines a result similar to that previously got with the two pairs, and thereby to save the expenses of one entire pair of engines—namely the low-pressure pair—for every four presses. The method of working the three-cylinder press is as follows:—the water from the pumps is admitted at first into the centre cylinder only, thus raising the follower F together with the two outside rams which are attached to it, the two outside cylinders, as their rams rise, being supplied with water by gravity from the supply tank to fill up the space left by the rising rams. When the resistance balances the pressure of the centre ram, the water from the pumps is admitted to the two outside cylinders, thus exerting the pressure of the three rams to finish the bale. After this press was brought out, very few of the old two-cylinder presses were made.

Now came a new era in the cotton-pressing business in India, caused by the opening of the Suez Canal. The measurement for vessels going round the Cape of Good Hope was 50 cub. ft. per ton weight, and for this measurement the power of the presses was ample; but when the Suez Canal was opened the measurement for vessels going by the new route was reduced to 40 cub. ft. per ton weight, and it was found that more powerful presses were wanted for compressing the bales to the required measurement. It was desirable to keep the length and width of the bales the same as before; but unless the hydraulic cylinders were made of some material superior to the cast iron up to that time employed, this could not be done, as the thickness of metal in the cylinders already took up all the space available in the construction of the size of press required. The writer therefore turned his attention to the adoption of steel cylinders in place of iron. When it was found that these could be obtained to withstand the necessary pressure, and that by this substitution the diameter of the three rams could at the same time be increased to 11 in., they were immediately adopted extensively. The new presses were made much larger and stronger than formerly, and weighed 40 tons each, the cotton box being increased in height to 14½ ft. or even 15 ft., as there was now

keen competition in the trade, and too much time had been spent in filling the box with the loose cotton. The introduction of steel cylinders led to the alteration of many of the old three-cylinder presses with 9-inch rams, the 9-inch cylinders and rams being replaced with 10-inch steel cylinders and rams to correspond, thus gaining 23 per cent. more power. The old two-cylinder presses with 11-inch rams were also many of them altered to three-cylinder presses with steel cylinders and 11-inch rams, so as to obtain the extra cylinder for economy, and also to obtain 50 per cent. more power.

Whilst these changes were taking place in some parts of India, in other parts the greater power required was being obtained by the aid of an auxiliary press or finisher, shown in Figs. 6 and 7, Plate 64, of great power, but only of short range. This press fitted with two 21-inch rams, and capable of exerting a pressure of above 2,000 tons, is worked in conjunction with the old presses, in which the bale is half packed and then transferred by means of an extractor E, Fig. 7, to the finisher, where the final compression takes place. Bales made in this manner however are hardly satisfactory, as the shape is not so square as when finished in one press, and consequently the measurement is not so good.

To obviate this objection the Compound Press has been designed, illustrated by the model and shown in Figs. 8 to 11, Plate 65, by which the bale can be finished to the size required without being removed from the press. The weight of this press is 53 tons, and its working is somewhat different from that of the other presses already described. The preliminary pressure is given to the cotton through a ram of 11 in. diameter, which forces the bottom follower F upwards to within say 5 or 6 in. of the size of bale required. The bottom follower carries with it whilst rising two side pillars or supports, which are locked as soon as it reaches the top of its stroke; these along with the 11-inch ram take the strain of the two 19-inch rams R R, which now finish the bale from the top, working downwards, and exerting a pressure upon it of 1,700 tons. The bale produced by this press, although not subjected to as great a pressure as when made by the auxiliary finisher, measures equally small in consequence of its better shape.

Up to the present time all the presses in India have had, on account of their height, to be placed in two-storied buildings, which were a great expense, especially up country. To obviate this, a Horizontal Press has now been brought out by the writer, the design being based upon the result of numerous experiments, from which he found that the pressure required to compress cotton, jute, &c., into half their natural bulk, is very slight, being only about 3 to 4 lb. per sq. in. of surface exposed to the pressure. The horizontal press, illustrated by the model and shown in Figs. 12 to 15, Plates 66 and 67, is fitted with three rams, Fig. 14, the centre one C being 9 in. diameter and the two outside ones R R each 14 in. diameter. The box B, in which the cotton or other fibre is placed, is reduced to half the ordinary length and increased to double the depth. A plate P descending by its own weight compresses the fibre in the box into half its original bulk, and having done so, forms the upper side of the box, and is secured in its place by locking bolts L. Horizontal compression is then given endways, first by the centre one of the three rams, until the resistance counterbalances it, after which the compression is given by all three rams. The bale when finished drops through a trap-door D at the bottom of the box upon a truck, and is removed along a tram or roadway. This press weighs 47 tons, and is capable of exerting a pressure of 1,100 tons.

Some doubt was felt by the writer about this press being suitable for packing cotton, on account of what is known as "cross-packing"; for, strange as it may appear, it is a fact that, if cotton is pressed, however slightly, in one direction, and then again at right angles, the bale will be "cross-packed," that is, the fibres throughout will be interwoven so as to render it impossible to separate them without force. Thus samples cannot be taken from the centre of the bale; and this is greatly objected to by the Liverpool merchants, although the "cross-packing" does not injure the cotton for spinning. The horizontal press was found to cross-pack, and consequently had to be abandoned for pressing cotton. In the meantime however its performances in packing jute, cuttings, &c., which had up to that time been packed in the vertical presses, were really extraordinary, two presses in one establishment turning out as many as 18 bales

each per hour, against 14 bales per hour for each vertical press with double the pumping power.

Naturally as the presses increased in size the engines for supplying them with water were increased likewise; but they were of a similar type to those first sent out, until the introduction of the compound press, when a very great improvement was effected by the writer, by increasing the number of direct-acting pumps from four (that is, one at each end of the piston-rods of the pair of engines) to twelve, as shown in the plan, Fig. 2, Plate 61, the effective number in operation at any time being reduced as required to overcome the increase of resistance in the press. The twelve pumps, one of which with its valves is shown in section in Fig. 3, Plate 62, are all the same size as the four formerly used, and are worked as follows. At the commencement of the operations, the pressure being slight, all twelve pumps are set to work until the resistance becomes too great, when one set of four pumps is relieved by opening a valve at the distribution box of the press, which allows the water to flow without pressure back into the tank from which it was drawn. The pumps now deliver less water at a higher pressure, until the resistance of the fibres in the press again counterbalances the power of the pumps; four more of the pumps are now relieved, and the engine with its remaining four pumps and full pressure of water finishes the bale.

In conclusion it may be stated that the direct-acting engines have lately been introduced into a warehouse in Manchester for working packing presses, hoists, cranes, &c., and are giving great satisfaction; they are also conducive to the comfort of all employed in the warehouse, as the vibration and noise caused by the gearing formerly in use have been entirely avoided.

Mr. Wilson exhibited working models of the several presses described in the paper, showing that the horizontal press was more convenient than the vertical presses, and enabled a greater number of bales to be pressed in the same time.

Mr. H. Shield said that, without going into the history of the gradual replacement of wooden screw presses and then of iron screw presses, and of the other improvements in presses that had taken place by the abandonment of the screw and lever press in favour of hydraulic power, he wished to draw attention to a diagram, Fig. 18, Plate 69, which he thought would be of interest as showing the work that had to be done in the press in pressing cotton to the density now required for the trade which had established itself especially between India and this country. In this diagram the curve was intended to represent the total pressure at various portions of the stroke in a compound press, something of the same description as the compound vertical press described in the paper, which might be taken to be really the only press that had any great future in it or that had done much in the recent past. The Watson press illustrated in Figs. 16 and 17, Plate 68, of which a working model was also exhibited, was one of which twenty-nine, manufactured by Messrs. Fawcett Preston and Co., Liverpool, had already been sent out to India within the last few years, their general features being as follows. The box was in cross section about 4 ft. by 1 ft. 4 in., with a rise of 14 ft. 6 in., and the lower cylinders were fitted with two rams of 6½ in. diameter. As soon as the box was filled and the hydraulic pressure turned on, these two small rams ran up very quickly, and, as was seen by the diagram, Fig. 18, so slight was the resistance in the box at the beginning of the pressing that for about the first 11 ft. the pressure gauge failed to record the pressure on the rams; the index of the gauge kept wavering, but did not indicate what the pressure was, the amount being very slight indeed until the first 11 ft. had been passed through, when there was a pressure of 2½ cwt. per sq. in. on the rams; and it was seen that from the eleventh to the twelfth foot the pressure increased from 2½ to 5 cwt. per sq. in., the corresponding total pressure on the bale being thereby doubled from 8 to 16 tons. In the next foot the pressure was again doubled, so that at the end of the thirteenth foot it was 10 cwt. per sq. in.; and at 14 ft. it was 18 cwt. The peculiar principle of this press was that at the moment when the lower follower, which was provided with teeth, arrived at the top of its stroke, a grid was thrust in sideways

between the teeth of the follower, and took the place of the follower in supporting the bale, the grid itself being firmly supported on the framework of the press. When the grid had taken its place, the follower immediately began to descend, and while it was descending the refilling of the box for the next bale was being proceeded with. The finishing pressure upon the bale left on the grid was given from the top downwards by means of two rams of 16 in. diameter working at a much higher pressure than the bottom rams. How rapidly the pressure increased in this final pressing was seen from the diagram, which showed that, when the top rams first began to work and had passed through only 3 in. of their stroke, the pressure upon them was 8 cwt. per sq. in.; at 6 in. the pressure was 10 cwt., at 9 in. 15 cwt., at 12 in. 25 cwt., and at 15 in. 45 cwt. per sq. in.; this final pressure at the end of the stroke gave a total pressure upon the bale of over 900 tons with two 16-inch rams. The work thus done in the top of the press was represented in Fig. 18 by the upper curve, which was also shown inverted by the dotted line and combined with the curve from the bottom of the press, so as to form one continuous curve for the whole operation. That showed pretty clearly what the work to be done was. How to do that work was a different question altogether; but he thought at any rate it was well to know what had to be done, namely to run up against a very light pressure to begin with, and to finish with a very heavy pressure. It was also seen that the real work of the press was measured by the final pressure required upon the bale; and that it would not be correct to compare one press for compressing bales to weigh 25 lb. per cub. ft. with another compressing to 40 lb. weight per cub. ft., and to suppose that their powers were at all in proportion to the density of the bale. That was not so: the entire measure of the power and cost of a press, and also of its commercial value, was regulated by the rapidity of its work and the final pressure necessary to be obtained for compressing the bale to the desired density; and the nearness with which the actual weight of the compressed bales could be made to approximate to their measurement was an important matter in the saving of freight, its importance having arisen, as mentioned in the paper, mainly since the Suez Canal had been opened.

One point alluded to in the paper, in which he thoroughly agreed, was that it was wrong to suppose that any pressures yet applied would injure the fibre of the cotton for spinning. He did not mean to say it would not be possible with very great perseverance to arrive at such a result; but it certainly had not yet been done, and it would not be done by any pressure not exceeding that which would make cotton bales weigh not less than their measurement; and as there would be no object whatever in compressing a bale so much as to make its measurement less than its weight, there was not the slightest fear of any such result being arrived at. There was a considerable interval yet left before equality of weight and measurement would be reached, which would require the cotton bales to be compressed to a density of 56 lb. per cub. ft., instead of the present maximum density of 40 lb. per cub. ft. If it were desired to increase the density to 56 lb. per cub. ft. he did not think there was any doubt it could be done; but he hardly thought it likely that the cotton would be wanted to be so compressed to the full extent of its dead weight; and he should imagine that a maximum density of 50 lb. per cub. ft. was about as much as shippers would like to carry for stowing purposes; he thought the cotton would stow better and make a better cargo at a density of 50 lb. per cub. ft. than at 56 lb.

In the compound vertical press that he had described, Plate 68, the salient feature was the movable grid upon which the partly compressed bale was supported under the finishing pressure of the top rams. Whether in the first pressing one ram or two rams or three rams were used was a matter of no importance: the point to be aimed at was to have a quick-working press, and one so arranged as to permit of the power being applied as nearly as possible in the same increasing ratio as the resistance arising from the compression of the bale. For that purpose the best pumping arrangement in his own experience had most certainly been found to be that in which there had been a considerable number of pumps, which could be easily thrown in and out of action, so that, in consequence of their number and of the facilities that they offered for adapting themselves to the varying resistance in the press, they could be combined together at

the beginning of the stroke for running the press up rapidly at first, and then their number could be reduced towards the end of the stroke, until at last there would be the minimum number of small pumps working at a high pressure against the resistance encountered by the top rams of the press in finishing the bale. The problem consisted in fact in supplying a great body of water to begin with at low pressure, and a very small body of water to finish with at high pressure. If the pumps were driven direct from the steam cylinder of the engine, it seemed to him—not as a matter of opinion merely, but simply as the result of the large experience already gained, particularly in India—that there must always be the same pressure of steam in the cylinder throughout the entire stroke, and it would be impracticable to work the engine at all economically by expansion, because there was a dead resistance on the pump rams which could not therefore be overcome by a varying power in the steam cylinder. It certainly did seem therefore that the proper and reasonable plan to adopt was not to put the pumps in a direct line with the cylinder, but to work the pumps from a crank-shaft driven by a connecting-rod and provided with a flywheel, which would take up the extra power at the beginning of the stroke and give it out again when it was wanted. That the practice of the writer of the present paper did assimilate to this view was shown by the fact that he had gone on increasing the number of the pumps from four to twelve. That pointed to the advantage of a large number of pumps; and as the result of practice with these pumps driven from a shaft he had found the best number of pumps for working a series of presses to be eighteen or twenty: the most recent number was eighteen, of which about half were 3 in. and the rest 2 in. diameter. The whole of the 3 in. pumps and part of the 2 in. pumps worked into the small cylinders of the press throughout their long stroke, and only two or three of the smaller pumps were worked at the end of the stroke of the press. The actual commercial result of this mode of working had been that, whereas with direct-acting pumps the average cost in fuel of pressing each bale was about 2*d.*, with pumps driven from a flywheel shaft in the way he had described the cost had been reduced to about $\frac{3}{4}$*d.* per bale. Not much of this saving could be due to the engine

itself, because it was a direct-acting non-condensing engine, water for condensation not being very available. Therefore so far as experience went he thought it was decidedly against direct-acting pumps; and it was desirable that this should be recognised, because the direct-acting plan was always preferred, wherever practicable, on account of being a simple and straightforward way of doing the work; but certainly so far as his experience had gone it was not the best plan in this case. He had no doubt about these results, because so many of these pressing companies in India, being limited companies, were required to publish their balance sheets; so that the figures for several years running could be obtained, and an average arrived at.

In the press which he had described, Plate 68, as soon as the bottom follower had got up to the top of its stroke the movable grid was thrown into its place and locked, for finishing the compression of the bale by the top rams, and then packing it by means of wrought-iron hoops put round: at the same time the bottom follower was descending again, and the attendants were beginning to fill the box for the next stroke. That was a considerable improvement, it seemed to him, over such an arrangement as had been described in the paper, where the bottom follower was locked at the top of its stroke, and had to wait there until the bale was completely finished by the top rams, which seemed to him a very serious drawback, losing the great advantage that a compound press should afford, of finishing the bale at the top of the press while the lower part of the press was being filled in readiness for the next stroke: that was the main point of difference between the two presses.

In reference to the number of bales per hour that could be packed, that was rather a difficult question to answer: it depended upon the power of the press and the rapidity with which the men could manage the lashing of the bales; no doubt the author of the paper had had the same experience as himself in that respect. The most authentic record of a day's work that he had ever received from India was in an instance where the inventor of the press under trial was by, and everyone was working well, and as many as 30 bales of jute were done per hour. But for regular work he thought it

would be fairer to take the rate at 20 bales per hour for jute, and for cotton not more than 18. It would he thought be very good work indeed for a press to continue to do 18 bales of cotton per hour; but the rate of progress depended upon the rapidity with which the men could lash the bales; that was what limited the speed.

As to the horizontal press described in the paper, which he thought extremely ingenious, he was only sorry that such ingenuity should have been thrown away so far as regarded cotton, because, as had been explained in the paper, the press was found to cross-pack the cotton, and cross-packed cotton would not do; and therefore so far as cotton was concerned the press might as well not have been constructed. So far as jute was concerned, he thought it was possible the difficulties of the press would be found even greater than with cotton, because jute was a material that required to be very carefully packed; it had to be packed in hanks, and the ends of the hanks had all to be in a certain position, namely at the end of the box; and if it were attempted to pack jute in two directions at right angles, such a tangled mass was produced that there was no means of dealing with it. For jute-roots it was different, and cross-packing would be of no consequence in that case; but for jute and for cotton, which were the two great staples of the work that had to be dealt with by the packing presses in India, the horizontal press he thought would be altogether inapplicable. No doubt one great object that was sought to be attained with the horizontal press was to get rid of the foundations: in any system of vertical press long cylinders at the bottom were a necessity of the economical action of the press; and it was natural therefore that it should be sought by placing the press horizontal to get rid of the difficulty of foundations, which entailed some outlay where there was a great quantity of water to be dealt with in the foundations; and although practically the difficulty was not usually a great one even where water was met with, still it was one that appeared desirable to be done away with, as would be accomplished by the introduction of the horizontal press. In the pressing of cotton and jute into bales however, even apart from the question of cross-packing, it certainly was not his own experience that horizontal pressure in itself was so good as vertical pressure,

because it was so difficult in pressing horizontally to get uniform density throughout the bale, which was apt to be pressed in lumps. He did not say that that objection could not be got rid of; but at present horizontal pressing was not desirable on that ground. In the compound vertical press that he had described the filling was all done from a pair of doors D D, Fig. 16, Plate 68, at the level of the stage on which the attendant stood, and the easing doors E E were just above. One man was thus in charge of everything, and there was no possibility of accident. Even if he were to turn on the pressure, for instance, at the time when it ought to be turned off, then the regulators which were attached to the pumps in a simple way would merely lift the suction valve of the pump off its seat, so that the pump would work no more; but this provision was hardly necessary, because the whole of the operations were entirely within the man's control, and the regulators were only put there as a matter of precaution.

Mr. B. Walker enquired whether the use of the accumulator had been tried in connection with the presses described in the paper, and what had been the result. If a large accumulator were used for a very low pressure, and a smaller accumulator for a higher pressure, and the pumps were going steadily on, it was known exactly what was the amount of pressure produced in the press, and the press could be made to go up at any speed desired. Many years ago he had made experiments in pressing rape-seed, and had found that with a steady pressure the quantity of oil got out of the seed was much more uniform than with the ordinary mode of applying the pressure suddenly. He was well aware that a certain amount of coal was thrown away by using the accumulator; but he should like to know whether it had been tried, and what loss took place. The action he was satisfied would be simpler by having one accumulator with the high pressure and the other with the low pressure, and turning either of them on so as to get any speed desired; in this way he had frequently lifted 150 tons 24 ft. in two minutes, and he did not see any difficulty in regard to speed: it was only a question as to what was the desirable speed to make the press travel at. In seed pressing,

if the seed were bruised too violently, and a high pressure were put on at once, the oil was not yielded to the same amount: it did not flow quite so easily as if the pressing began gradually and a higher pressure were put on afterwards.

Mr. Wilson replied that in cases where only one press was used he considered the accumulator was essential, and it had been applied in such cases; but where there were as many presses as would keep the pumps constantly going, the accumulator was then thrown out: there was no use for it where the engines were already going constantly. That principle he had followed out as much as possible, in cases where at first presses had been used with two cylinders which required high and low-pressure pumps. With such presses arranged in sets of six, the low-pressure pumps were first applied to run up one press as far as they could, and then the high-pressure pumps were applied to finish the bale, thereby running up one press with a low pressure while the bale in another press was being finished with high pressure. As long as there were plenty of presses to keep the pumps constantly going, he had never considered that any advantage was gained from the accumulator; but in cases where only one press was employed he had considered that it was essential to have an accumulator, so as to utilise the power of the pumps during the time that the bale was being lashed and the press got ready for starting to work again.

Mr. Christopher James mentioned that a few years ago he had tried the use of a small accumulator in connection with half a dozen presses for pressing stearine and lard oil, &c., and it acted very well indeed. The pressure employed was 2 to $2\frac{1}{2}$ tons per sq. in. at first, running up the presses very quickly; but to his surprise it was found that the long-continued action of the accumulator with a pressure of only 16 or 17 cwt. per sq. in. did the work very much better.

With regard to the use of horizontal direct-acting engines, it appeared to him that was a very neat arrangement, and it must not be forgotten that there was a good flywheel combined with it, as represented in Fig. 1, which acted as an equaliser; so that the difficulty

which seemed to be apprehended by a previous speaker did not exist in practice. He enquired whether for the packing of the rams in the presses described in the paper the ordinary cup-leathers were used, or any other packing of that kind. In the case of an accumulator working rapidly up and down, he had found from time to time great difficulty with the ordinary cup-leather; and he should like to know what pressure could be worked at with a packing of hemp or flax or anything of that sort; it seemed to him if that kind of packing could be used, it was a much simpler mode of packing than the cup-leather, as the ram need not be taken out for packing. With regard to the difficulty that had been mentioned as to the cost of the foundations with vertical presses, it seemed to him that, the whole strain being entirely self-contained in the presses, the question of whether they were put upright or horizontally did not signify. If there were a vibratory action or anything of that kind, it would be different; but the whole strain in the press being self-contained, its mere weight of 50 tons was no very great amount to be carried upon the foundations.

Mr. Wilson replied that he had found a great error had been introduced and seemingly perpetuated by long practice, through the cup-leather being made too broad, which caused a great amount of friction against the ram; and moreover when the leather was so very broad, the friction of the leather on the ram tended to carry it along with the ram and crush it, and it was very apt to crack; in fact the broad leathers lasted only a very short time. But if the leather was made very narrow, and supported by the curved groove in which it rested, it might last for an indefinite period; there seemed to be no limit to its durability, provided there was nothing detrimental in the kind of water used. Cup-leathers he always used above a certain pressure; up to 600 or 700 lb. per sq. in. hemp or cotton packing could be used, but beyond that pressure cup-leathers seemed to be the best packing for standing the pressure.

As to the use of direct-acting engines for working the pumps employed to supply the hydraulic presses, it was seen from the drawing that there were twelve pumps worked by a pair of direct-acting engines coupled at right angles, with a heavy flywheel to turn

F 2

the centres. In first starting a press the whole of the twelve pumps were employed, and as long as the pressure was light these twelve pumps delivered almost a constant flow into the press; when the pressure increased, four of the pumps were thrown off, not by any mechanical disconnection, but simply by opening a valve to allow the water to escape from them into the supply cistern, so that there was no time lost and no jarring took place in throwing them off, the opening of the valve simply relieving the pressure and allowing the water to escape through the distribution box. Again, if it was necessary to have the pumps so arranged as to throw off another four when the pressure was further increased, that was also done by another valve opening from the delivery pipe of the next four pumps to the supply cistern. By that means a pressure was obtained sufficient to overcome the resistance of the cotton until the bale was finished, and it was found in many cases that in this way from 60 to 70 lb. weight of cotton could be compressed into a cubic foot. That was more than sufficient, because if the cotton were made as heavy as water it was quite enough. Indeed 40 cub. ft. to the ton was what was allowed by the Suez Canal, so that if the pressing was carried beyond 56 lb. weight per cub. ft. no advantage would be gained thereby. That extent of compression could be accomplished quite easily by the presses described in the paper with a water pressure of 2 or 2½ tons per sq. in. According to his own experience he had not found a disadvantage from the use of direct-acting engines, but the reverse; the direct-acting plan was attended with simplicity of action, and there were no joints or joint-pins to wear and get slack, so that with valves and pumps made in the proper proportions the wear and tear was very small. He had never found any advantage from using eccentrics to work the pumps from the crank-shaft; with a great number of pumps it increased the complication, and was no advantage over direct action; so that he preferred the direct-acting arrangement, which was much simpler in every way.

Mr. E. A. Cowper observed that the deep foundation which had been spoken of as required by the compound vertical press described in the paper would not be needed if the press were constructed with

the smaller ram at the top, inverting in fact the arrangement shown in the drawing. Many years ago he had made a press having a 7 in. ram with 7 ft. 6 in. stroke at the top, to come down and give a light pressure upon the bale, and the compression was then finished by a large ram 16½ in. diameter with 3 ft. 6 in. stroke at the bottom of the press, which worked upwards and gave 400 tons total pressure upon the bale; that press was made to pack cotton in India, and it acted very well. There was no doubt great economy in working first with a small ram and then with a large one; he quite agreed that that was a very excellent arrangement, and a press so constructed might either be used vertically or be laid down horizontally. The plan adopted in the horizontal press described in the paper, of merely dropping a weight upon the box to press the cotton down, seemed at first sight an admirable one; but in consequence of the cross-packing it would not do in practice. The cotton must not be pressed first sideways and then endways, but must be made into one flat pancake (so to speak) by pressing in one direction only; then it was all tied together, and when the bale was hooped it would not burst apart. If that was not attended to, and if there was cross-packing, the bale tended to burst sideways, and the cross-packing injured the cotton besides. Therefore he thought a compound press like that described in the paper, either vertical or horizontal, was the right plan.

Mr. R. H. Tweddell, referring to the remark that with a great number of small pumps the varying resistances would be met by varying the number employed, thought that any advantage due to this was to a great extent counterbalanced by the increased complication. He very much preferred the direct-acting pumps described in the paper; but he went even farther, and considered that the number of parts might be still farther reduced and simplified. By this plan certainly a much larger steam cylinder would be involved, but at the same time the number of valves would be materially reduced. Taking an ordinary baling press for pressing goods, such as was in use in Manchester, with a 14 in. ram and a 4 ft. stroke, the pumps must make about 450 double strokes for each single stroke of the press,

and each double stroke of the pump involved raising and lowering two valves, so that for 450 strokes there would be 900 valve beats, which meant, especially at the high pressures, great wear and tear. If the same work in the press could be done with one stroke and one valve beat, it would only be carrying out the direct-action principle advocated in the paper, and was he considered an economical method. The objection which had been raised, that while the resistance varied during the stroke of the press the steam cylinder must be filled with steam at full pressure, could to a very great extent be overcome by using the exhaust steam to work the pumps during the greater part of the press stroke, during which the power required was small.

With regard to the packings employed to stand the heavy pressures, he used hemp packing for accumulators loaded to 2,000 lb. per sq. in., the accumulator making 5,000 or 6,000 and in some cases 7,000 double strokes of 3 ft. each per day of eight hours. Cup-leathers he had found would not stand under conditions of such continuous working, but there was not the slightest difficulty with the hemp. There was a very slight loss, he was aware, through increased friction when hemp packing was used; but it was a question of keeping the apparatus working constantly. The time spent in putting in new cup-leathers was an infinitely greater source of loss than that due to any increase in friction involved by use of hemp.

Mr. H. Davey considered the durability of a cup-leather depended entirely on how it was applied. In some experience that he had had in the use of cup-leathers for quick-running hydraulic pumping engines working under considerable pressure, he had found at first that the cup-leathers gave way very soon; and on investigation he found that they gave way from a springing or buckling action which took place in the leather, from its not being properly supported. At first it had been the custom to drop the leather into the recess, as shown full size in Fig. 22, Plate 70, and simply support it underneath with a little ring or filling piece A, sometimes of wood and sometimes of cast-iron or of brass, rounded to fit the inside of the leather. It was found that the leathers invariably gave way about the point B, and it appeared to him that they gave way

there from a buckling action like that occurring in the working of an accordion or of the leather in a pair of bellows: during the upstroke of the ram the leather would be forced hard against it by the pressure until the top of the stroke was reached, and then on the reversal of the stroke until the ram had received a little motion the leather would be stretched in the opposite direction. By simply putting a brass bush or saddle C, Fig. 23, under the leather so as to support it effectually underneath, turning the saddle exactly to fit the leather, he had succeeded in getting the leathers to last three or four times as long. Another point which he had found contributed to the life of the leather was to provide a very long bearing for the ram in the cylinder at D, Fig. 24, immediately below the leather. When thus put in with a more accurate support, the leathers now lasted three or four times as long as they formerly did when not supported accurately enough.

Mr. J. Platt asked whether any difficulty had been found from the thin edge of the back supporting ring E, Fig. 22, springing against the ram and thereby ultimately breaking across at the point B. He had found this to be the case with a large cast-iron ram with a cup-leather in a recess made to fit it, like the diagram.

Mr. H. Davey replied that if the ring E was thinned to a very fine edge it would give way; but there was a point which was found in practice to answer best. The edge of the ring was brought down to a certain distance to support the leather as far as possible, but it must not be tapered to a perfect feather edge; if it were so, it was liable to damage in working.

Mr. E. J. C. Welch mentioned that during the last few years he had, in conjunction with Mr. R. H. Tweddell, made a number of experiments with packing rings shaped in the same U form as cup-leathers, but made of various kinds of material, including vulcanised india-rubber, gutta-percha, and also leather; and he had found that if a packing ring must be used at all there was nothing like the leather ones. The india-rubber seized on the ram, as he had

expected it would do, and it was torn to pieces in a few minutes. The gutta-percha did not seize, and it lasted fairly well, possibly one-fifth of the time that leather would; but it had this advantage, that when it was worn out it could be remoulded; it was simply necessary to put it into boiling water, add more gutta-percha, and then mould it into a fresh ring. With these gutta-percha rings he had had a very curious experience. The exterior of the ring had at first been moulded with full square corners at F F in Fig. 21, Plate 70, while the interior was shaped so that the edge bearing against the ram was nearly twice as thick as the inner edge. When these rings were put into the hydraulic machines, although they were a good fit they were not "tight"; they leaked, not much, but sufficiently to show that they were not acting on the principle on which lipped rings were supposed to act. These identical rings were then taken out and put in a lathe and rounded at the corners, as shown in the drawing; and as soon as ever that was done they were perfectly tight; showing that for a ring to work at the best advantage it must be free from the ram at those corners. This would also show that the tightness of the ring did not depend upon the direct pressure of the water behind it driving it out laterally against the ram, but upon the pressure acting radially to the curve, and resolved into a direction tending to straighten out the semi-circular curve of the bottom of the ring, and so giving a thrust in the lateral direction against the ram, as further shown by the fact that the wear took place only at the point G next to the ram. A gun-metal liner J had also been made to fit exactly to the shape of the inside of the ring, as shown in the figure; and there were a series of holes drilled right into the root of this liner to admit the water well into the interior of the ring. This however was not found to make a very great difference, because even without these holes the ring would never fit so tight upon the liner J, but that the water would pass in behind it. As to the leather rings, the great defect in many of the sections employed had been found to be that already pointed out by Mr. Wilson, namely that they were made much too deep: it was astonishing how shallow a ring would work with perfect success; and of course the less material there was used the better, so long as it would answer the

purpose effectually. From a large number of experiments he (Mr. Welch) had deduced the following formulæ, which gave what he had found to be the best proportions for leather packing rings:—

$$T = 0{\cdot}156\ R^{0{\cdot}279} \qquad D = 2{\cdot}5\ T \qquad W = D$$

in which R = diameter of ram, T = thickness of leather, D = total depth of ring, W = width of ring outside when of U section. It was absolutely necessary that leather rings should not be strained in the moulding; and he had found that it was the straining of them by moulding them too much at one effort which really damaged the leather to such an extent that it was liable to crack soon afterwards, and to have no durability. He had found it necessary to make a series of moulding boxes of successively increasing depth, and to mould the rings by gradual steps; when they passed through the whole series of moulding boxes, much better and more permanent leathers were obtained, and the extra time expended on the moulding was as nothing when compared with the extra duration of the rings. Ultimately however he had entirely done away with the cup-leather rings, and had adopted hemp packing instead; and he used nothing else now. The hemp packing he had used up to a pressure of one ton per sq. in., and it was found to be perfectly tight. He had hemp packing which had been at work for a year without being replenished at all, and there was as yet no sign of leaking.

Mr. E. T. Bellhouse said that, having had some experience of packing presses with steel cylinders working up to a pressure of 5 tons per sq. in., he had found very considerable difficulty some years ago, when the steel presses were beginning to be used, in procuring in the then state of the steel manufacture steel cylinders which would stand with any degree of certainty the required pressures; and not having made the cylinders himself he had in some cases sustained considerable loss in consequence of their not having been sound. The steel cylinders however that were now manufactured by Messrs. Whitworth and by Messrs. Nasmyth at Patricroft he believed were eminently successful and very desirable indeed for hydraulic presses. It was now a long time since he had used steel cylinders himself, and he should have used them more,

only that he had not been able with confidence to recommend waiting for steel cylinders to replace broken iron cylinders in hydraulic presses employed in Manchester warehouses. For India he had manufactured two packing presses, which had succeeded admirably, and had a good many advantages. One advantage was that instead of being a considerable height and requiring high buildings, they were about half the height of the presses then in vogue, the pressure being given sideways in the first instance, and then perpendicularly as a finish. An objection was urged against them on the ground that in some unexplained way the fibres of the cotton or other material packed in these presses were so jumbled up together that they broke, and the fibre was destroyed; but that had not been substantiated by the practical working of the presses, and in fact the experience of the bales which were turned out proved that it was an entire fallacy. In those presses the pumps had not been worked upon the direct-acting principle shown in the drawings accompanying the paper, but by shafting and gearing from the steam engine to the pumps, which were worked just in the same manner as the original hand presses used to be supplied by hand power, the more recent presses having been brought to their present state of perfection gradually, as in the case of so many other inventions, through improvements made gradually by a great number of inventors; and he believed there were warehouses in Manchester where the pumps for the presses were worked on the same principle. The pressure was first applied laterally, by two horizontal rams of 7 in. diameter on opposite sides of the press, which were locked at the end of their stroke, and then the finishing pressure was given by a vertical ram of 16 in. diameter; that arrangement saved half the depth of foundations required where the whole of the pressing was done in the vertical direction alone. In a subsequent form of press, which he had designed in conjunction with Mr. W. J. Dorning, it was intended to give the pressure in the vertical direction alone, by means of a large central cylinder with 16 in. ram, and two smaller cylinders, one on each side of the larger. The two smaller rams acting direct upon the table of the press raised it first of all to the extent of their stroke, while the large ram was left behind at the bottom of the press; when they had risen as high as they could

go, a cylindrical block or distance strut, carried by an arm that was centred on one of the press pillars, was swung round and inserted beneath the table of the press upon the top of the large ram, the pressure of which was thus transmitted to the table for finishing the compression of the bale.

With regard to the use of leather packing rings, he had found that the ordinary cup-shaped leather ring, placed in a very shallow groove, was the best plan of packing; that required no supporting rings of metal either outside or inside; and when proper leather was used and the packing well made, it was suitable for any diameter of ram that might be required, and answered the purpose admirably.

Mr. J. G. Chapman wished to draw attention to the difference between the direct-acting pumps employed for working the hydraulic presses described in the paper, and the pumps worked by cranked shafts for the Watson press made by his own firm, which had been described by Mr. Shield. It had been ascertained that, in the packing establishments where the pumps with 6-inch stroke driven by cranked shafts were working, it cost three farthings in fuel to pack a bale of cotton or jute; while in the other establishments with direct-acting pumps having 3-ft. stroke, it cost twopence. That was a great difference, and it was desirable to seek the cause. It was known that this could not lie in the difference of workmanship in the two kinds of pumps, because the work sent out to India must be good, or it could not stand. Granting therefore that the two combinations were equal in workmanship, there must be something in the design of the two sets of pumps to make them so different in the consumption of fuel. Having been personally interested in designing the pumps worked by cranked shafts, he had come to the conclusion that the reason was the difference of speed at which the water was driven before the plungers in the two kinds of pumps. In both cases heavy flywheels were used; and it was therefore clear that at some portion of the stroke the plunger propelling the water when worked direct-acting must go at the rate of the crank-pin; and as this went 50 per cent. faster than the steam piston, it followed that,

if the engine was running at 50 rev. per min. or a piston speed of 300 ft. per min., as all such engines did at times, the crank-pin must be travelling at 450 ft. per min.; so that, if the pump was directly connected to the piston, as those described in the paper were, the highest speed of the water through the valves would be 450 ft. per min., assuming the water-way through the valves to be equal to the area of the plunger. Even at a low pressure that would be an enormous speed; but at high pressures, such as 50 cwt. per sq. in., so great a speed was a very serious matter: whereas in the Watson pumps driven by cranked shafts, as the stroke was only 6 in., the maximum velocity, when running the engine at the same speed of 50 rev. per min. as in the other case, was only 75 ft. per min. instead of 450. The consequence of this difference was found in a four months' comparative trial to be that the coal consumption was small in the one case and large in the other.

With regard to the number of beats made by the pump valves when short-stroke pumps were employed, there were eighteen pumps working of 6 in. stroke to each of the Watson presses; and in order to run the bottom press-rams up through their entire 15 ft. stroke, each valve in each pump made only thirty beats, which he considered was not an excessive number.

Mr. G. Lewis mentioned that in the Ashcroft packing press, made by Mr. W. Turner of Salford, the pressing was performed by a combination of steam and hydraulic power. From the curve which had been exhibited of the increasing resistance to be encountered in compressing a bale of cotton, it was seen to be necessary that in the first application of the power the speed of the motion should be as rapid as possible, while the pressure was low; then as the press ram rose, the bale became more dense, and it was necessary that the pressure should be increased proportionately. To meet these requirements, in a press that he had previously made on the ordinary plan there were as many as four sets of six pumps, twenty-four pumps in all; and to each of these pumps there was attached a separate and independent apparatus for knocking off, for enabling each pump to work independently of the rest, according to the varying pressures

required, as indicated in the diagram exhibited; and as the pressure rose, the pumps were automatically knocked off in succession. That press had worked with very good results; but as a previous speaker had pointed out, there were in that plan a great number of valves, all of which were liable to get out of repair and required incessant looking after. Now in the design of the compound system upon which the Ashcroft press was constructed, the object aimed at had been to provide for what was very observable in the curve of pressure, namely the rapid rise required in the press ram at starting; and it had been thought that no more rapid rise could be obtained than by the direct employment of steam power itself for the first part of the stroke. This had accordingly been accomplished by placing on the top of the press proper a steam cylinder 45 in. diameter, alongside of which were placed a set of pumps, six in number, arranged in three pairs of different sizes, the steam cylinder and pumps being of the same stroke, namely 9 ft., and the pump plungers being all attached to a crosshead on the top of the piston-rod. From this crosshead were carried down two side-rods coupled to a similar crosshead below the bottom of the press, arranged for lifting the rams proper that carried the table of the press. By this arrangement the first lift of the press, through the full 9 ft. stroke of the steam cylinder, was given direct by the steam: no quicker power could be obtained than by that means; no mode of applying the power to force water could beat that. The press cylinders themselves were filled by a supply of water flowing in by gravity direct from the tank while their rams were being lifted by the upstroke of the steam cylinder. In the return or downstroke of the steam cylinder, with the full steam pressure on the top of the piston, the six pumps came into action, forcing the water into the cylinders of the main press rams; and all six pumps went down as far as they could, that is until they were nearly brought to a stand-still by the resistance of the bale. The attendant, observing this, immediately knocked off the two largest pumps, of 6 in. diameter, and afterwards the two of the next size, leaving at last only the two smallest pumps of $3\frac{3}{4}$ in. diameter to finish the bale with the heaviest pressure: thus there was no power lost, the increasing pressures being successively put on by the

attendant just as required. One press of this kind was doing 45 bales per hour; and a larger press with the same 9 ft. stroke of the steam cylinder had done as many as 50 bales per hour. This seemed almost impossible, because in the ordinary presses with only one box, like those described in the paper, it was necessary to fill that box between the pressing of each bale, and the number of bales that could be turned out was thus limited by the rapidity with which the box could be filled. To overcome that difficulty in the press which he had described three boxes were arranged on a revolving platform centred upon one of the side pillars of the press, and there were three sets of men, two sets for filling and one set for baling; immediately the pressing of the bale was finished in one box, the platform was turned round and the filling of the empty box was begun while the second box was being pressed and the filling of the third was being finished. In that way the press was enabled to do as many as 50 bales per hour; and it would be seen that the whole number of strokes required to finish each bale was only two, one up and one down.

In regard to packing leathers, he could bear out what had been said by Mr. Wilson about their being generally made too deep; and he asked what he had found in his practice was the necessary depth of a packing leather for a ram of 9 in. diameter.

Mr. Wilson remarked, in reference to the idea which had been expressed respecting the difference between what were called direct-acting pumps and those worked by eccentrics, that, although the rams of the pumps described in the paper were worked direct from the steam cylinder, requiring no connecting joints or shafts, still they were guided by exactly the same motion as the pumps worked by eccentrics, inasmuch as their motion was guided by the crank-pin of the engine, and that crank-pin if made large enough would become an eccentric, and would give the same motion as was got with the eccentric, only with much less surface in the crank-pin. Thus the twelve pumps of the engine shown in the drawing might be supposed to be worked with four eccentrics at right angles to one another: they began their stroke slowly and ended it slowly, exactly the same as if actually worked by eccentrics. The real difference between

these pumps and those driven by eccentrics, with which they had been compared by a previous speaker, was that, instead of having only a 6 in. stroke like the pumps worked by eccentrics, these pumps had a 2 ft. stroke; but if a pump with 6 in. stroke had to make as many strokes as would make up the difference in delivery between that and a pump of the same diameter with 2 ft. stroke, the former would have to make four strokes for one of the latter, and the consequence would be that the number of beats of the valves and every other motion in the smaller pump would be increased in the same proportion. In any other respect he could not understand where the difference lay between the direct-acting rams guided by the motion of the crank-pin, and those receiving identically the same motion through the eccentrics: in either case a very heavy flywheel might be employed, for working the steam more expansively; but so far as concerned the effect upon the motion of the water there could be no difference between the pumps worked direct from the piston-rod and those driven by a separate eccentric to each ram. In either plan the motion began at nothing and ended at nothing; and in the larger pumps the maximum speed attained was equal to the circumferential speed of the crank-pin, just as in the small pumps it was equal to that of the eccentrics. Thus he considered that either mode of working would give as satisfactory results as the other; but his experience was that it was desirable to avoid complication as far as practicable, and on that account he thought the simpler the arrangement was, the better.

With regard to the breadth of the packing leathers, he had found a great breadth was so much against the power of the leather to withstand crushing, and the leather was so liable to crack and break wherever it had become at all crushed, that he thought the narrower the leather was, the better, so long as it was water-tight: it could not be too narrow if the water did not escape. A breadth of only 1-8th or 1-4th inch, as shown full size in Fig. 20, Plate 70, he had found would secure the tightness of the leather quite as effectually as if it were an inch broad. The narrower the leather was, the longer it lasted, because the leather was pressed against the ram with the full pressure of the water behind it; so

that the broader the leather was, the greater was the total amount of friction to be overcome, and consequently the force tending to crush the leather longitudinally was proportionately greater, and caused it to be crushed by the friction of the ram. Hence he had had rams covered with gun-metal, whereby less friction was occasioned, because the gun-metal surface was smoother; and by that means economy was obtained in the leather, for where one leather working against a cast-iron ram would be destroyed in a few days, another working on gun-metal would last for months. That was a matter of great importance in the rams: at the bottom for a length of about 3 ft. from the end, where the heavy pressure came on, they were all covered with gun-metal and highly polished, whereby the wear and tear of the leathers was much reduced.

The President proposed a vote of thanks to Mr. Wilson for his paper, which had given rise to a very spirited discussion upon its subject.

The vote of thanks was passed.

The Meeting then terminated.

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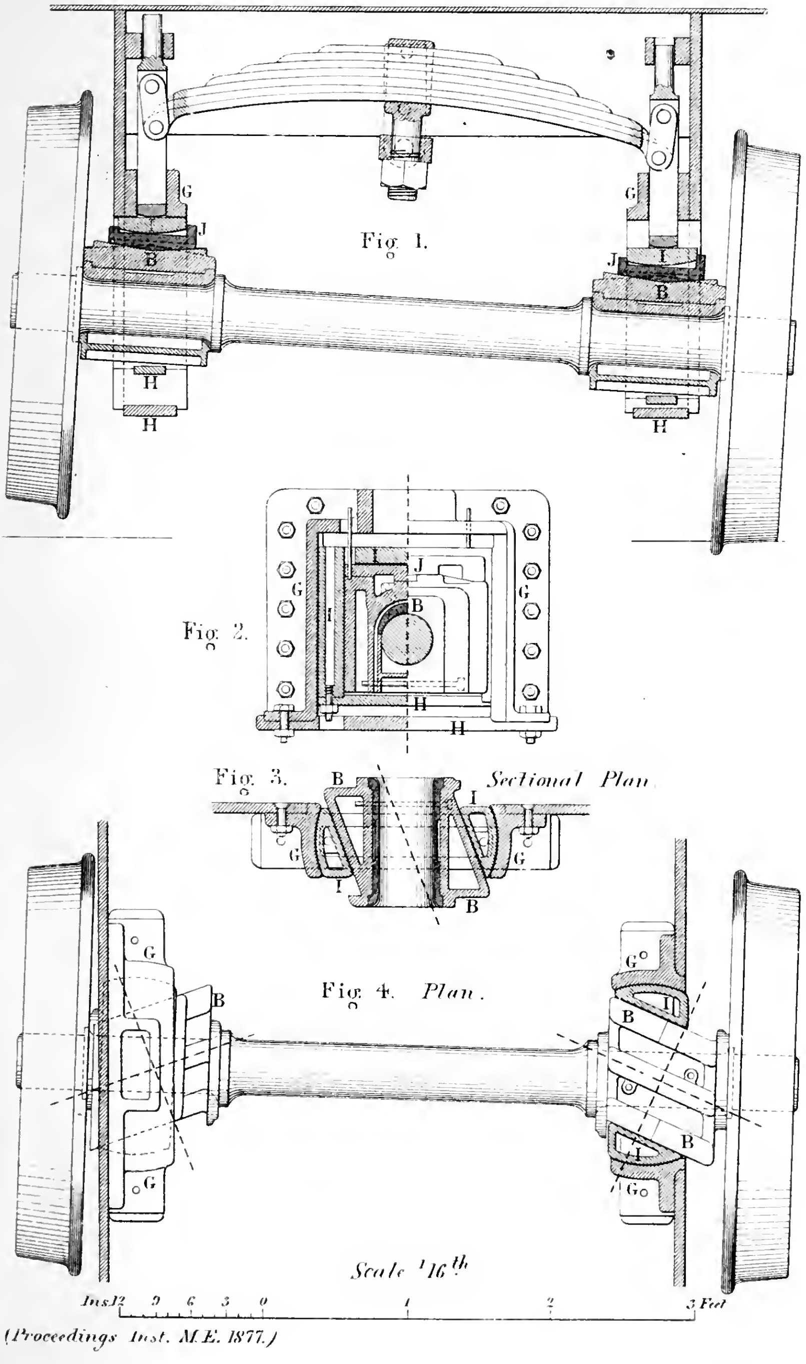
1877.



(*Proceedings Inst. M.E. 1877.*)

Fig. 5.

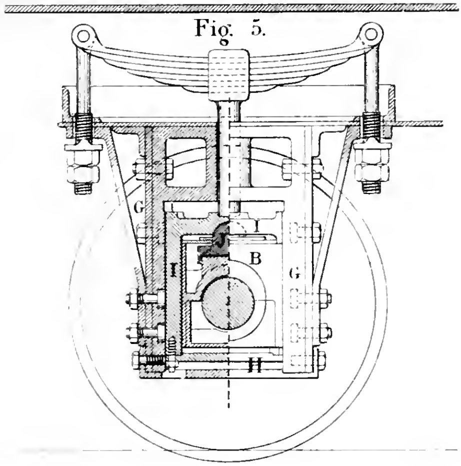


Fig. 6.

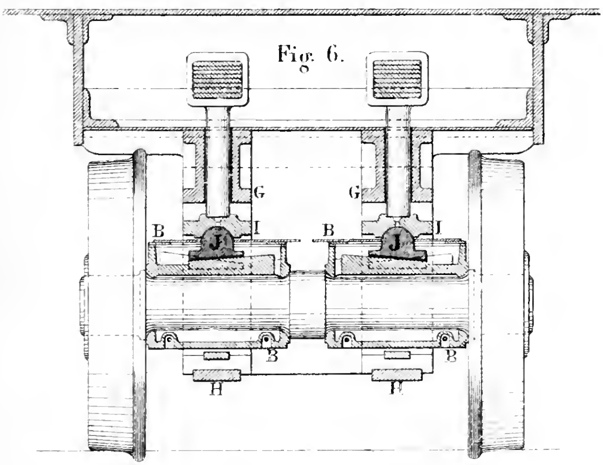
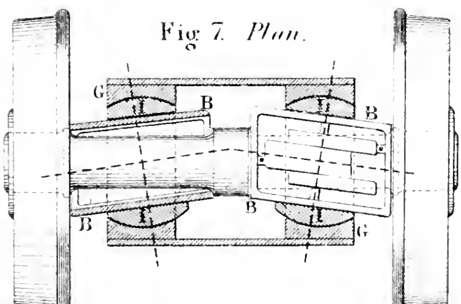


Fig. 7. *Plan.*



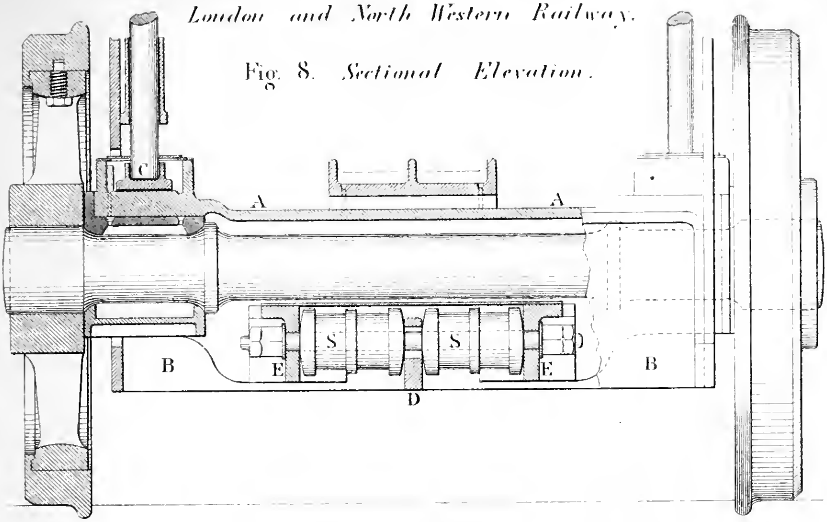
Scale 1/16th

Ins. 12 9 6 3 0 1 2 3 Feet.

(Proceedings Inst. M. E. 1877.)

London and North Western Railway.

Fig. 8. *Sectional Elevation.*



Transverse Sections.

Fig. 9. *At* XX.

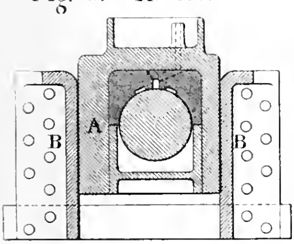


Fig. 10. *At* YY.

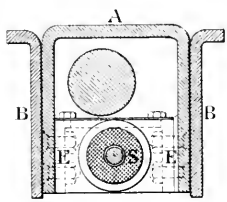


Fig. 11. *At* ZZ.

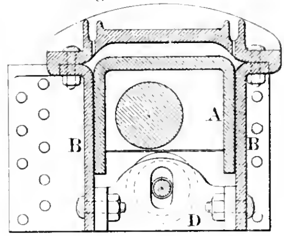
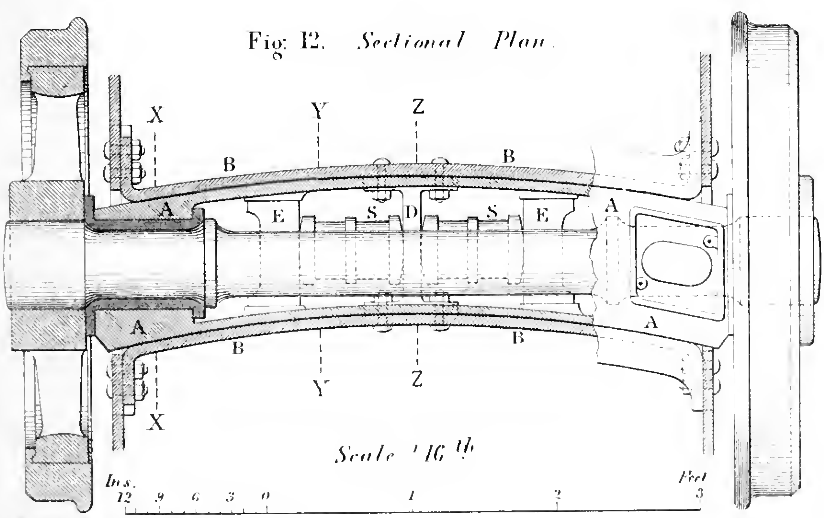


Fig. 12. *Sectional Plan.*



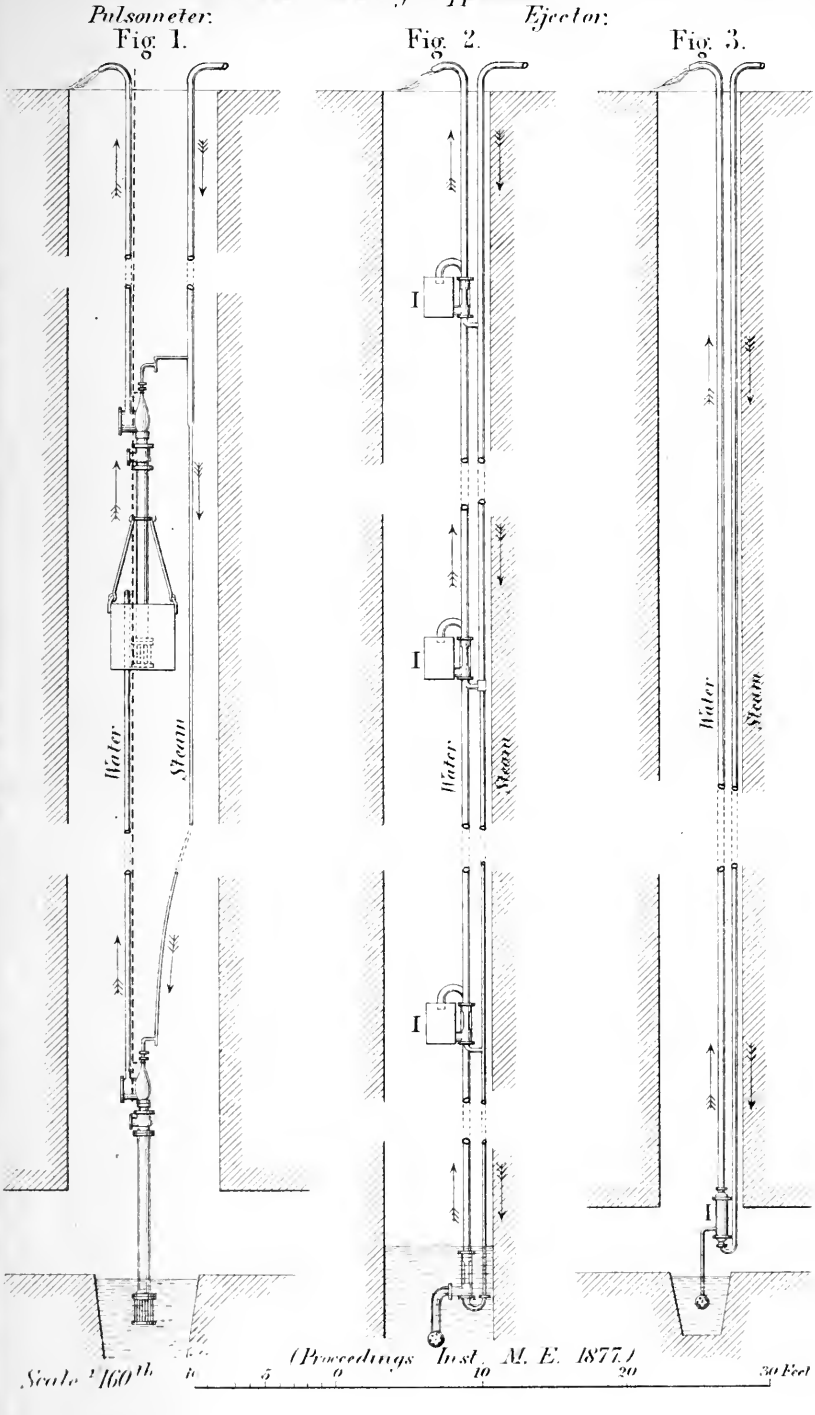
Scale 1/16th

Ins. 12 9 6 3 0 1 2 3 Feet

(Proceedings Inst. M.E. 1877.)

APPLIANCES FOR MINE ACCIDENTS. *Plate 51.*

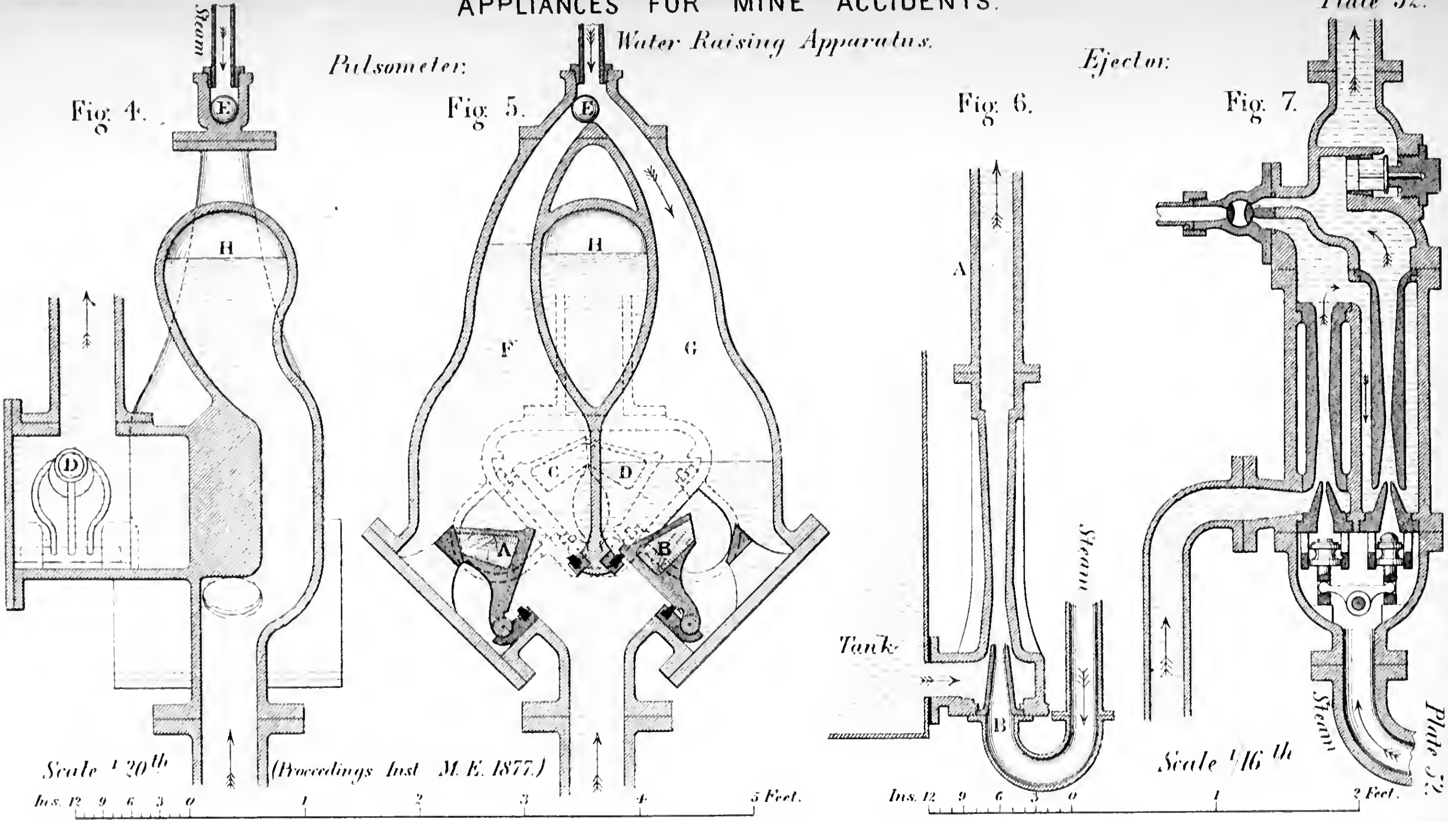
Water Raising Apparatus.



APPLIANCES FOR MINE ACCIDENTS.

Plate 52.

Water Raising Apparatus.



APPLIANCES FOR MINE ACCIDENTS. *Plate 53.*

Water Raising Apparatus.

Fig. 8. *Centrifugal Pump*

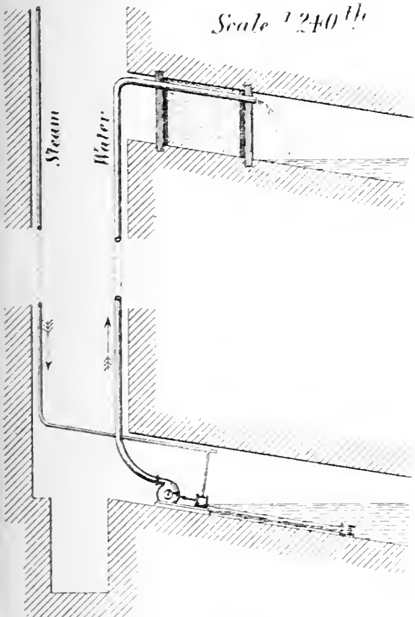


Fig. 9. *Direct-acting Steam Pump.*

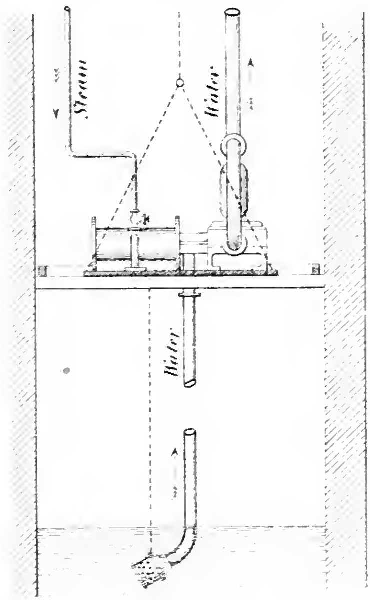


Fig. 11.
Direct-acting Steam Pump

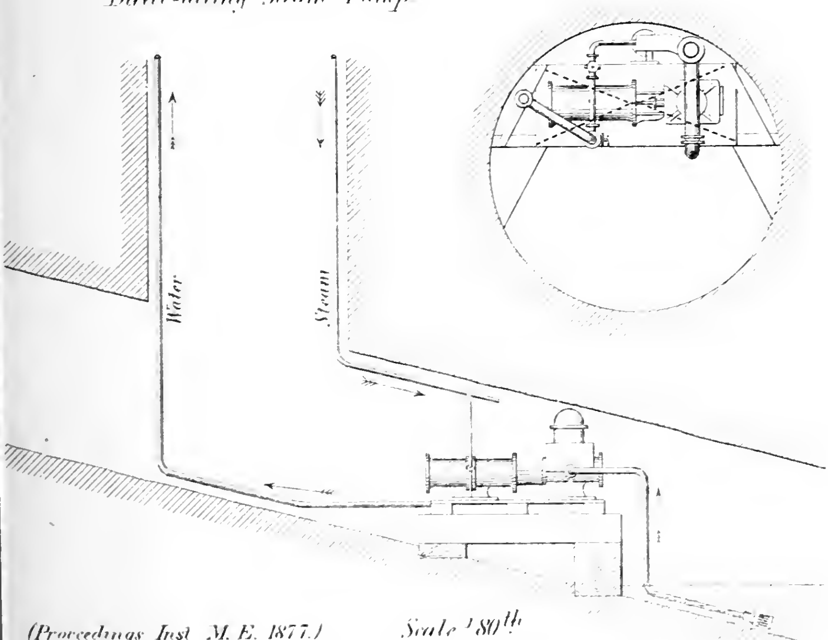


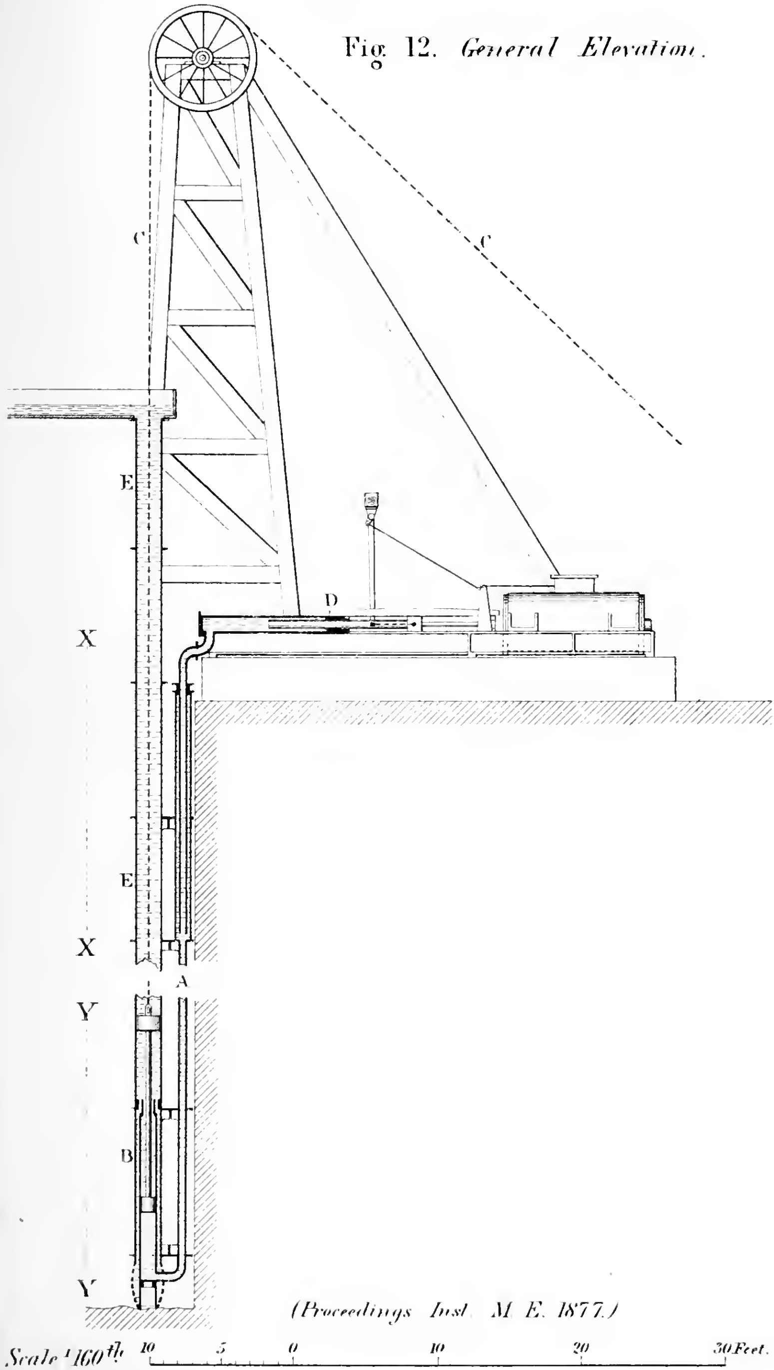
Fig. 10. *Plan.*

(Proceedings Inst. M. E. 1877.) *Scale 1/80th*

0 5 10 15 20 Feet.

Water - Spear Pump.

Fig. 12. *General Elevation.*



(Proceedings Inst. M. E. 1877.)

Water-Spear Pump.

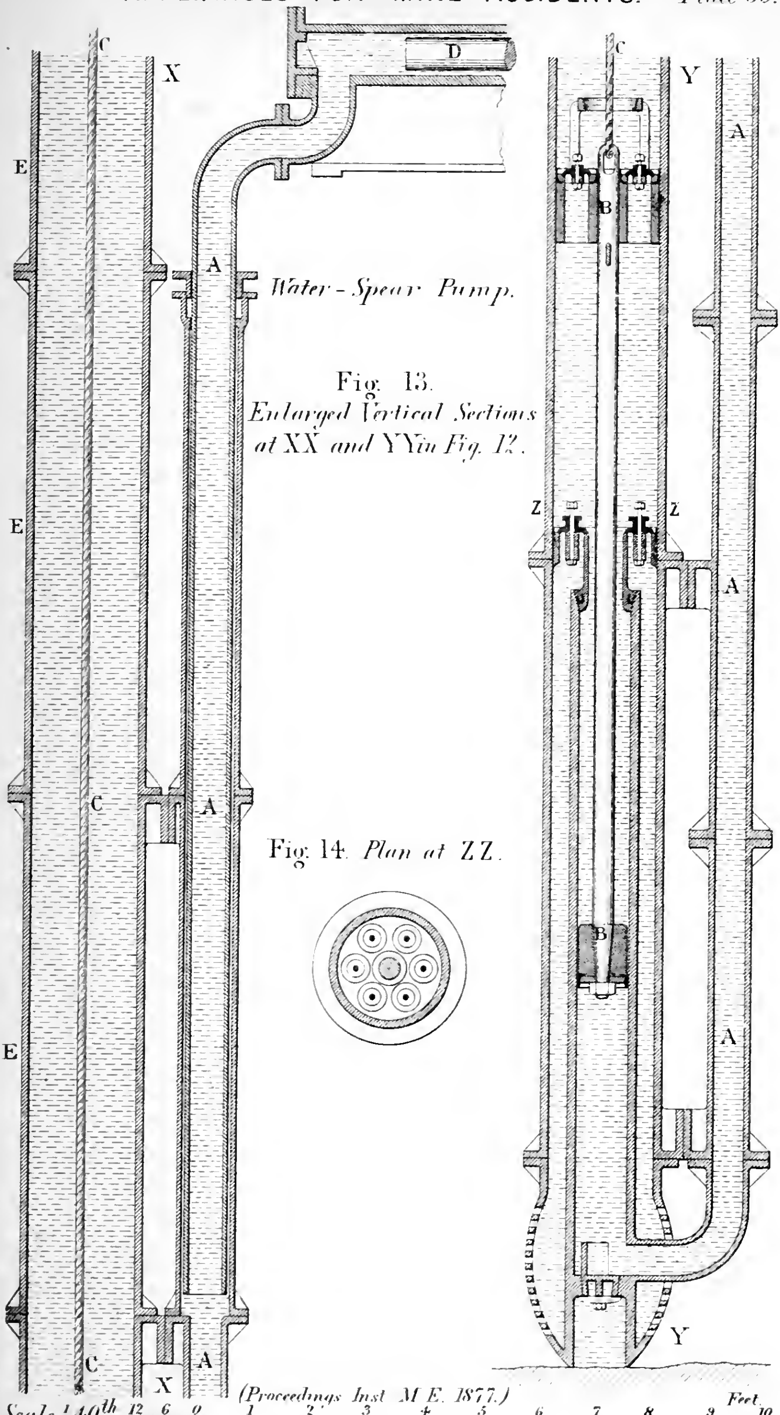


Fig. 13.
Enlarged Vertical Sections at XX and YY in Fig. 12.

Fig. 14. *Plan at ZZ.*

(*Proceedings Inst M.E. 1877.*)

Scale 1/40th. 12 6 0 1 2 3 4 5 6 7 8 9 10 *Feet.*

APPLIANCES · FOR MINE ACCIDENTS.

Double-acting Hydraulic Engine.

Fig. 15. *Longitudinal Section.*

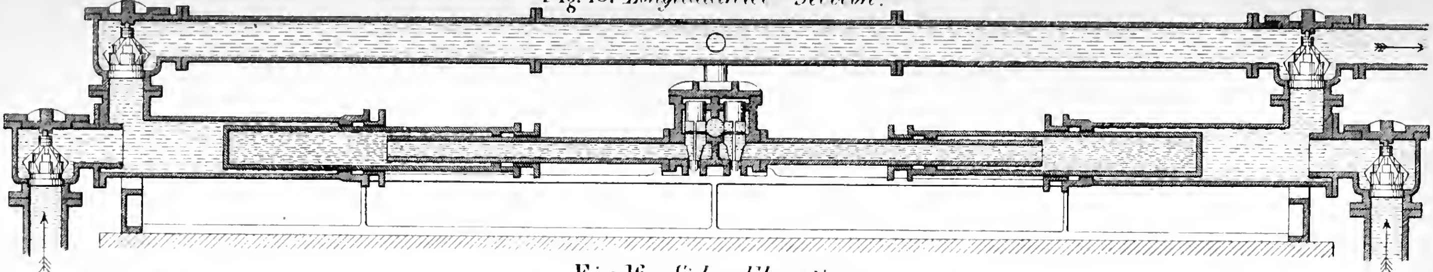


Fig. 16. *Side Elevation.*

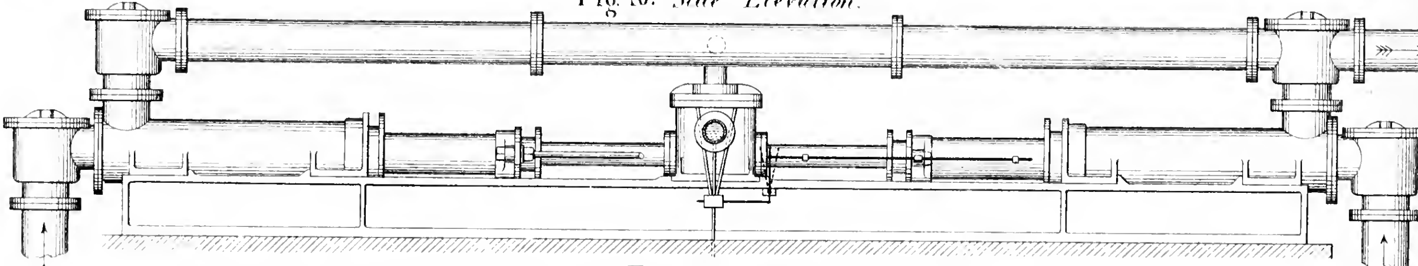
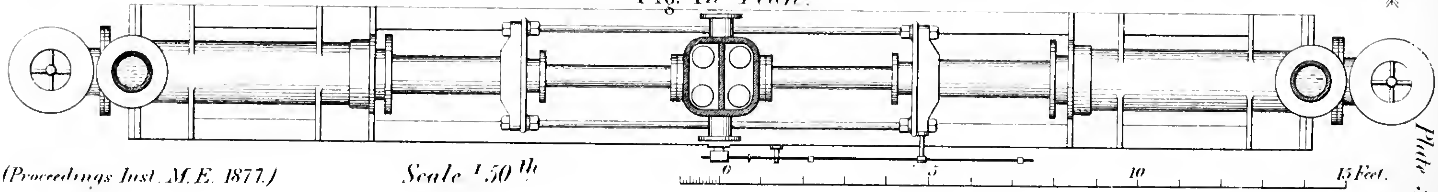


Fig. 17. *Plan.*



(Proceedings Inst. M.E. 1877.)

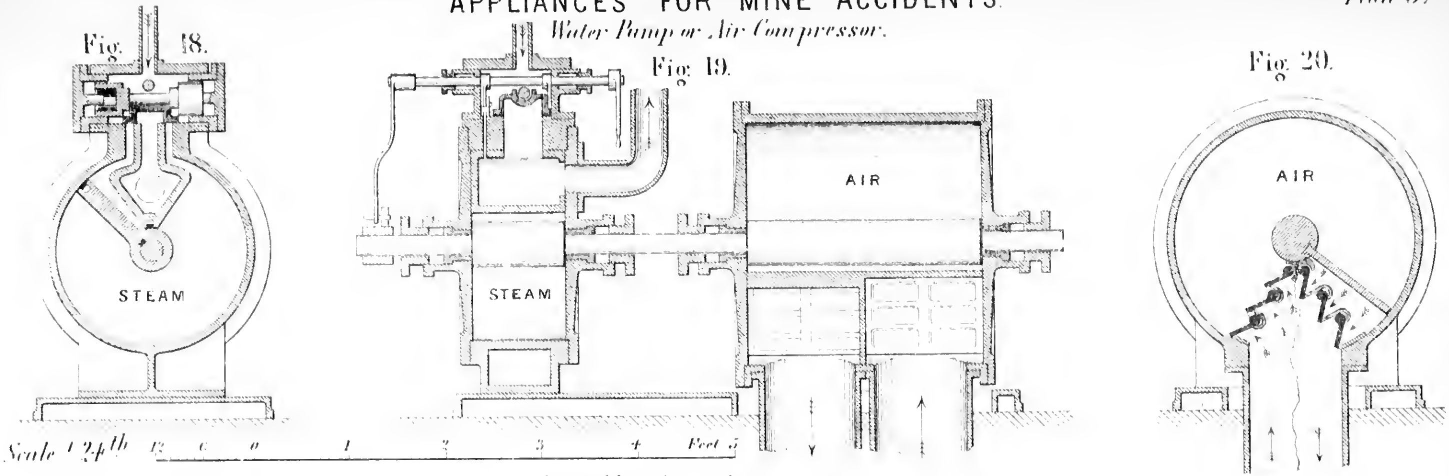
Scale 1/50th

Plate 56.

APPLIANCES FOR MINE ACCIDENTS.

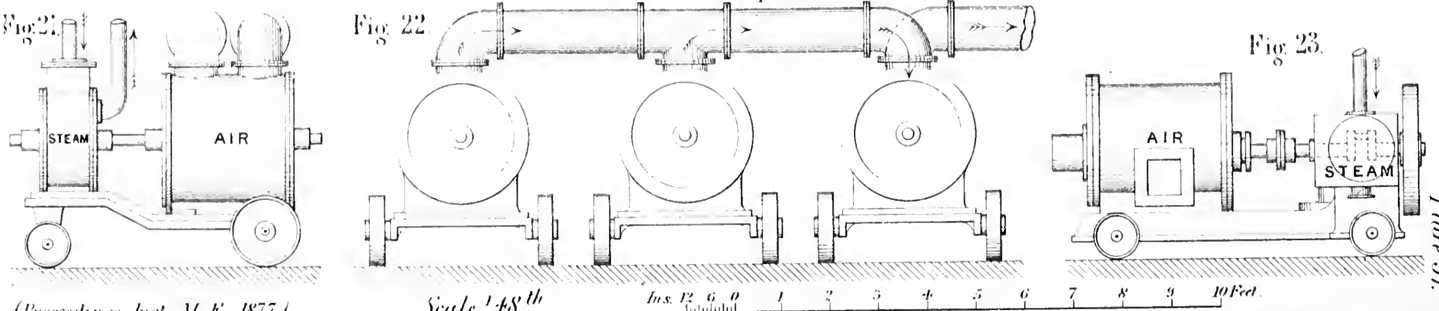
Water Pump or Air Compressor.

Fig. 18. Fig. 19. Fig. 20.



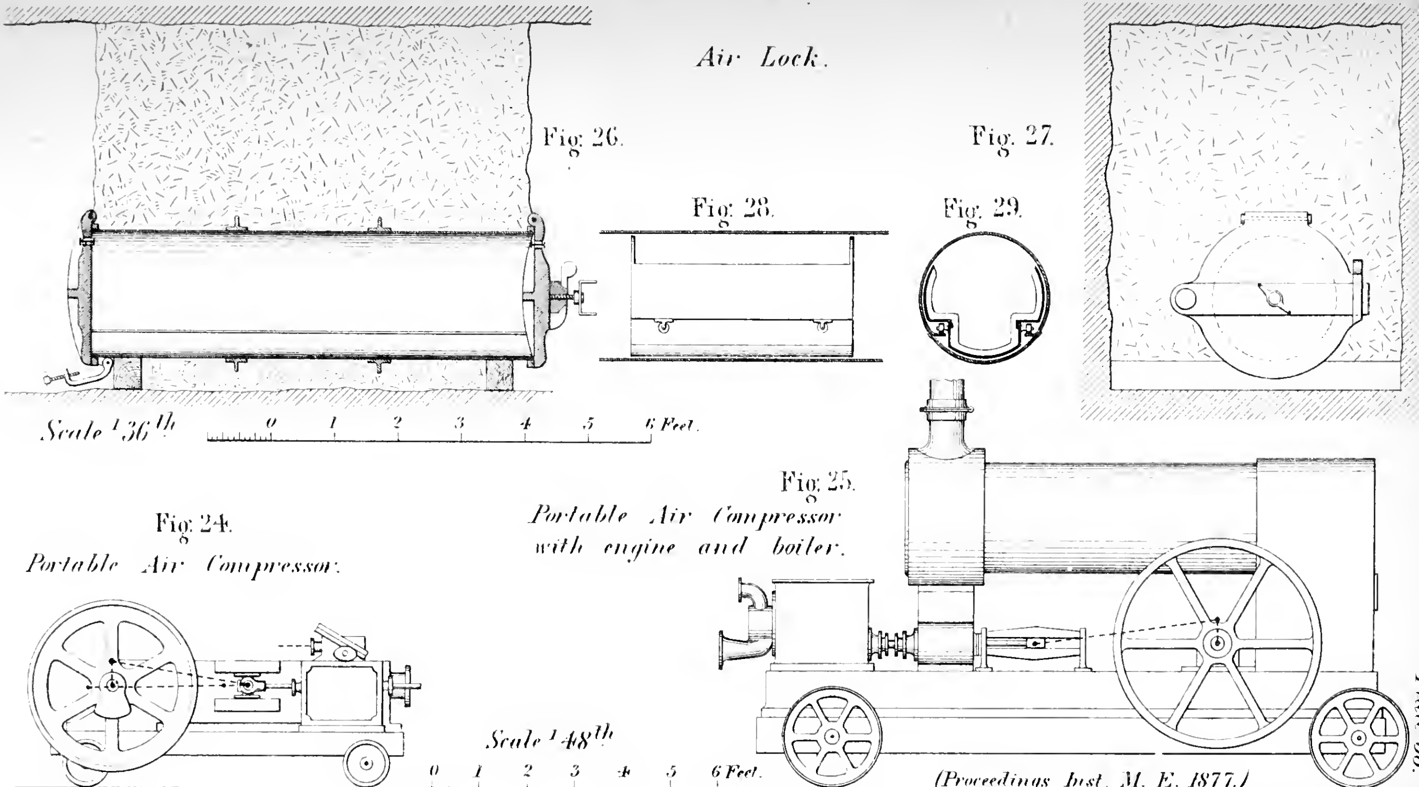
Portable Air Compressors.

Fig. 21. Fig. 22. Fig. 23.



(Proceedings Inst. M. E. 1877.)

APPLIANCES FOR MINE ACCIDENTS.



(Proceedings Inst. M. E. 1877.)

Plate 58.

Portable Boilers.

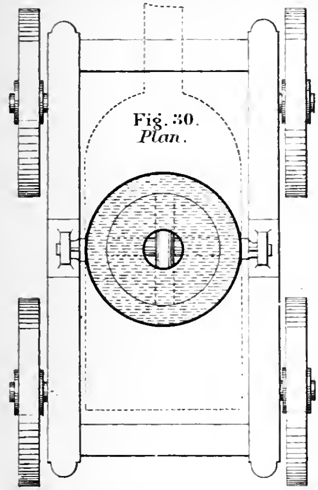


Fig. 30. *Plan.*

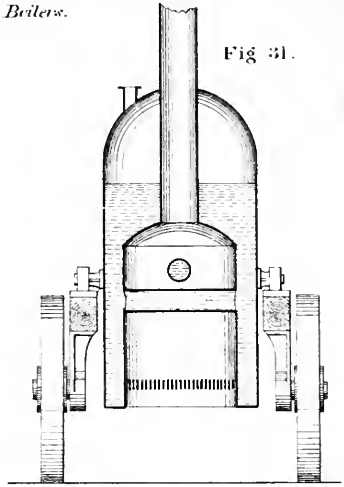


Fig. 31.

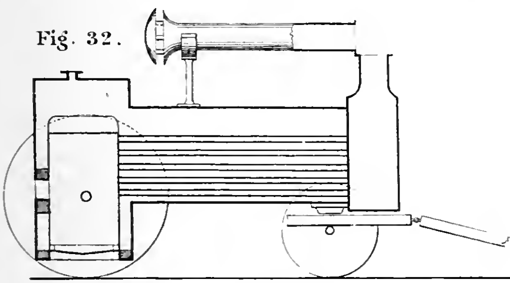


Fig. 32.

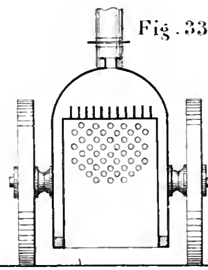


Fig. 33.

Scale $1/60^{th}$ — 0 1 2 3 4 5 6 7 8 9 10 Feet

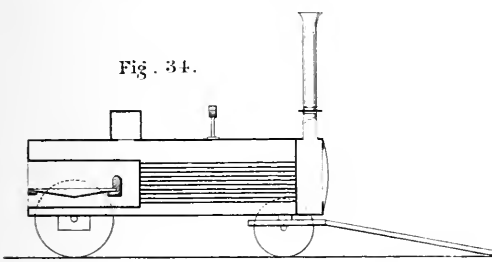


Fig. 34.

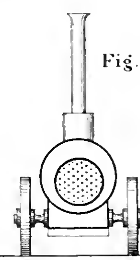


Fig. 35.

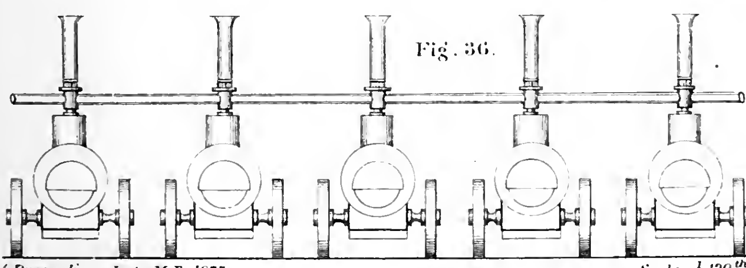


Fig. 36.

Scale $1/120^{th}$

Portable Winding Gear.

Fig. 37.

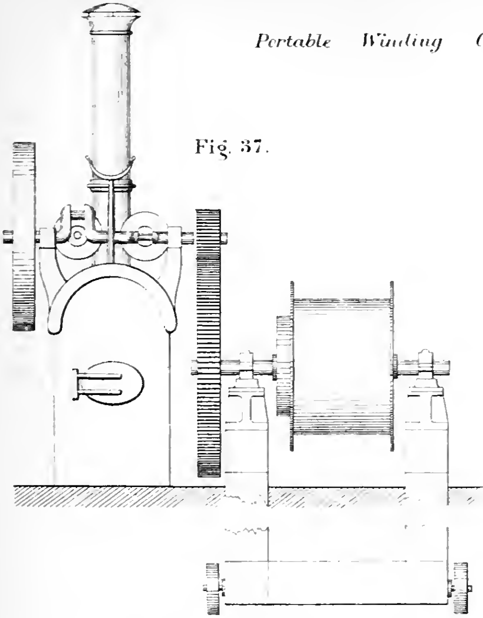
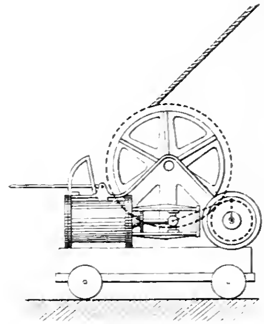


Fig. 38.



Scale 1/60th 1 5 10 Feet

Fig. 39. *Pit-head Frame*

Scale 1/120th

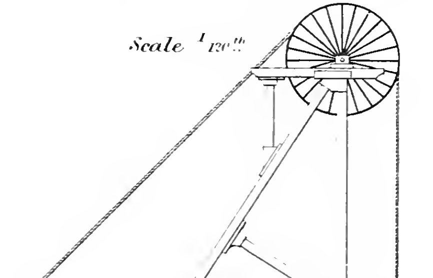
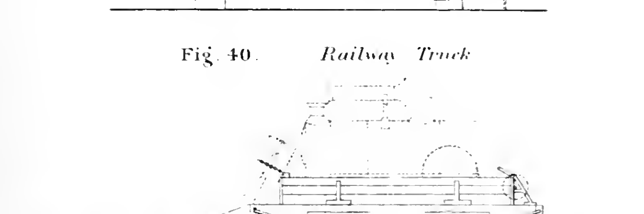


Fig. 40. *Railway Truck*



Scale 1/120th

HYDRAULIC PACKING PRESSES.

Wilson's Horizontal Direct-Acting Engine and Pumps.

Fig. 1. *Elevation.*

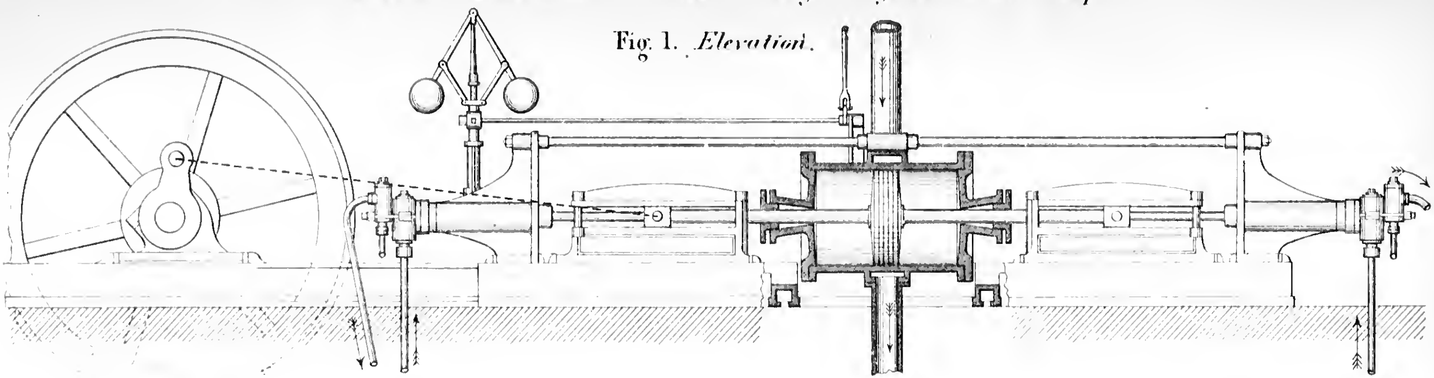
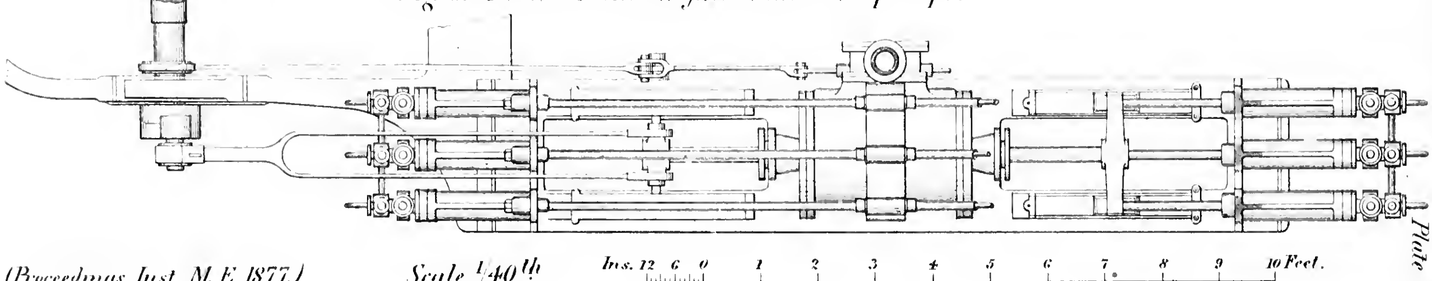


Fig. 2. *Plan of one engine with six pumps.*



(*Proceedings Inst. M. E. 1877.*)

Scale 1/40th

Plate 61.

HYDRAULIC PACKING PRESSES.

Wilson's Horizontal Direct-acting Pumping Engine.

Fig. 3. *Section of Pump and Valves.*

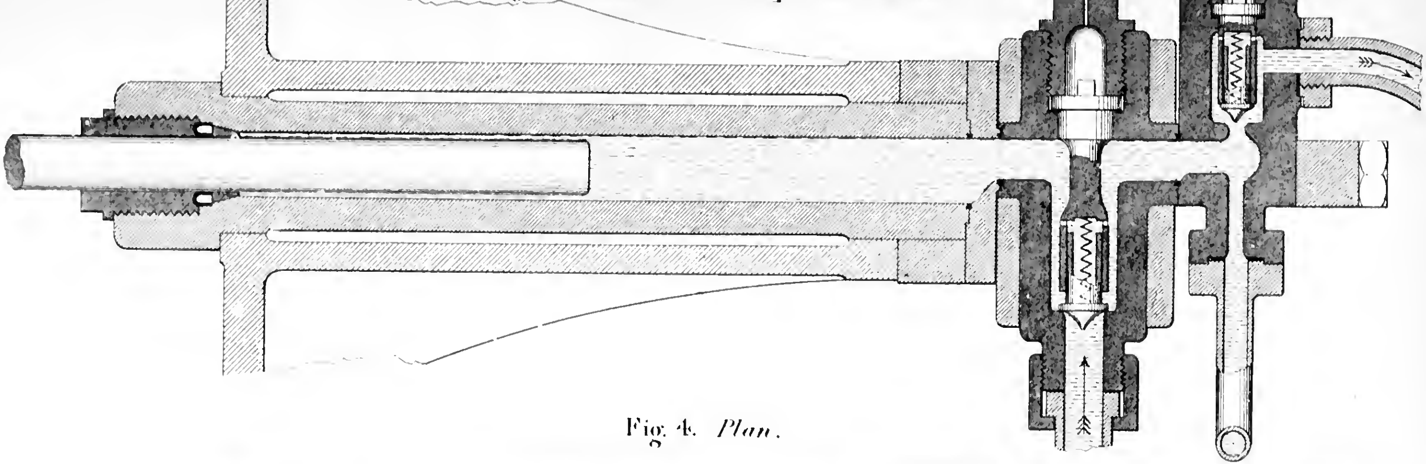
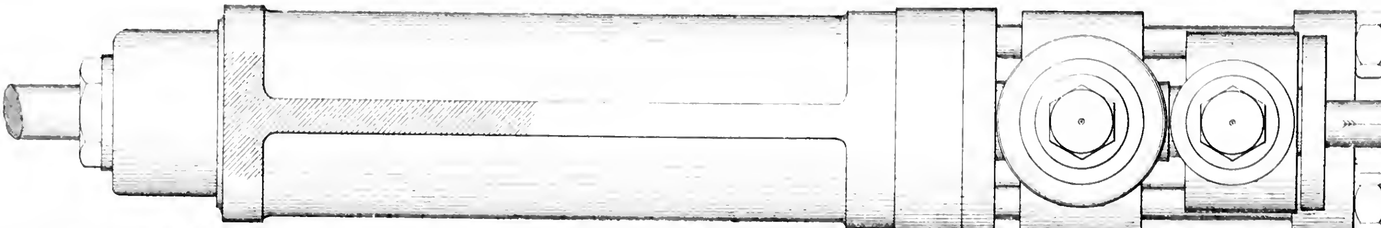


Fig. 4. *Plan.*



(*Proceedings Inst. M.E. 1877*) *Scale 1/6th* Ins. 12 9 6 3 0 1 Foot.

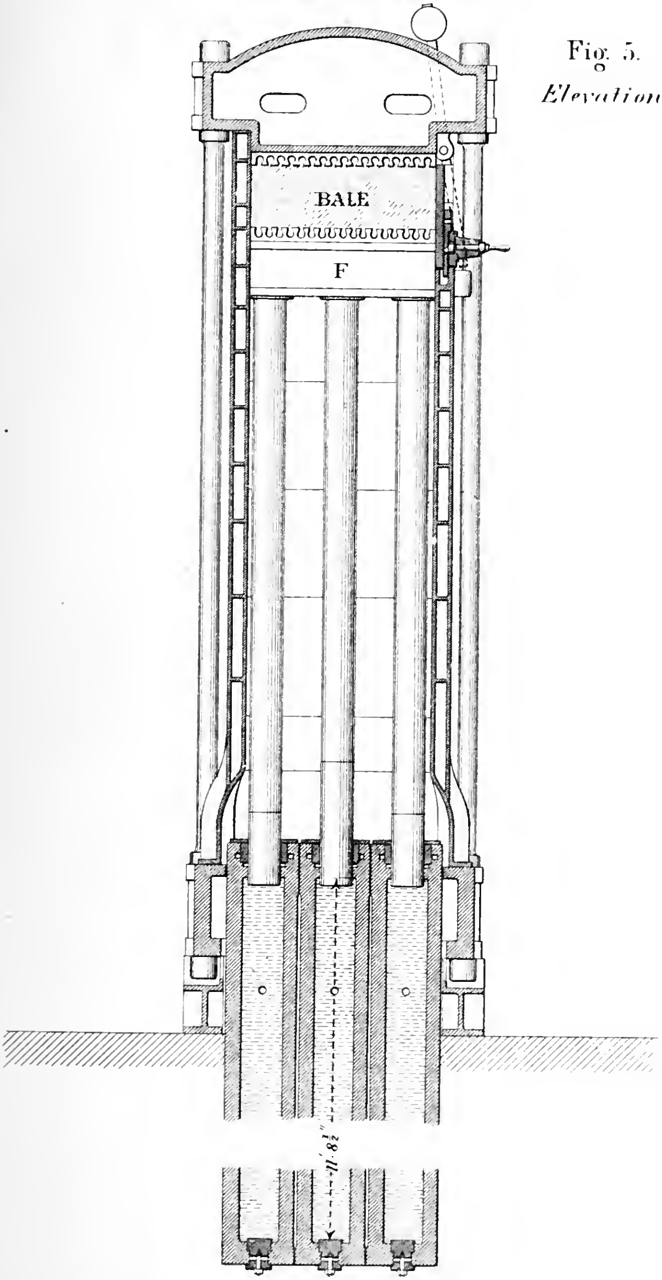
Plate 62.

HYDRAULIC PACKING PRESSES. *Plate 63.*

Wilson's Three-Cylinder Press.

Fig. 5.

Elevation.



(Proceedings Inst. M. E. 1877.)

Scale 1/50th.

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 Feet

HYDRAULIC PACKING PRESSES.

Wilson's Finishing Press.

Fig: 6. *Front Elevation.*

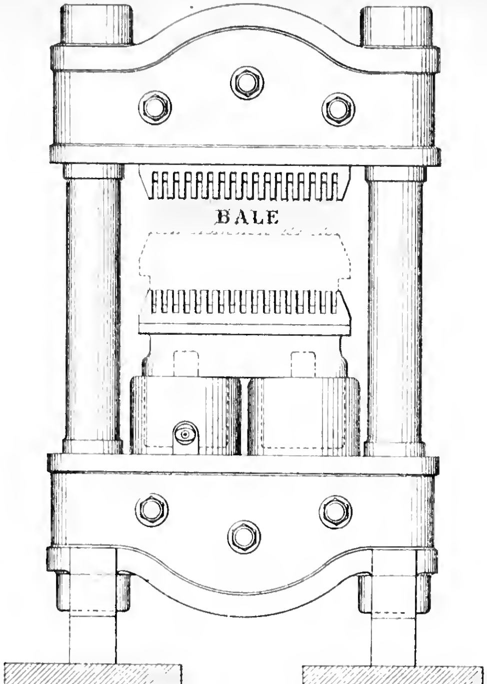
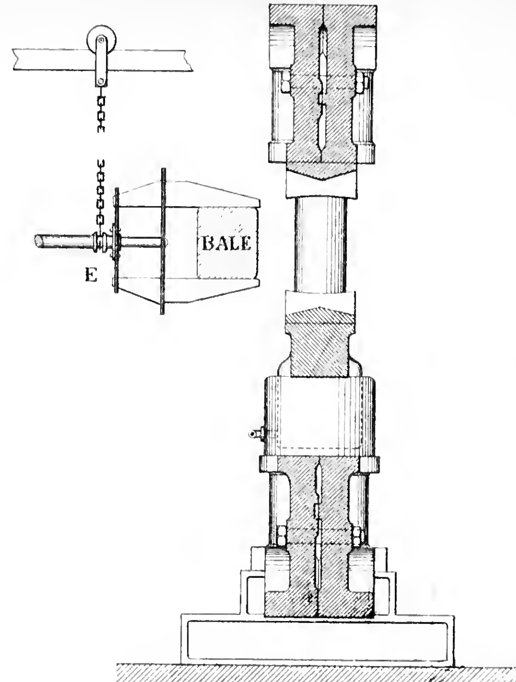


Fig. 7. *Vertical Section.*



(Proceedings Inst. M.E. 1877.)

Scale 1/50th.

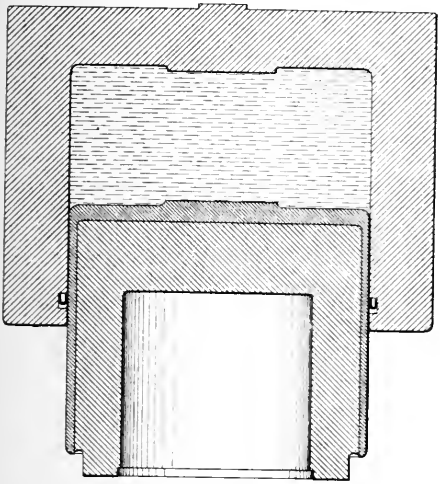
Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 *Feet.*

Plate 64.

HYDRAULIC PACKING PRESSES. *Plate 65*

Wilson's Compound Vertical Press.

Fig. 11. *Section of one of Top Rams.*



Scale 1/12th

Fig. 8. *Vertical Section.*

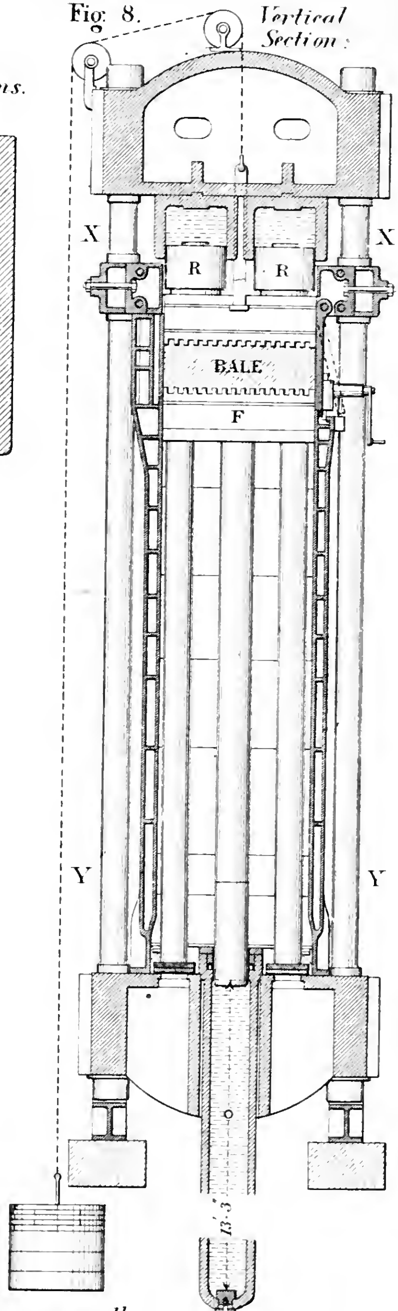


Fig. 9. *Sectional Plan at XX.*

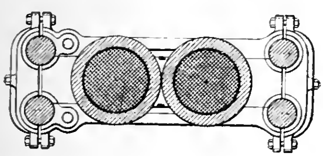
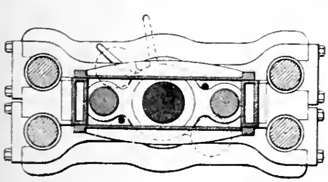


Fig. 10. *Sectional Plan at YY.*



(Proceedings Inst. M. E. 1877.)

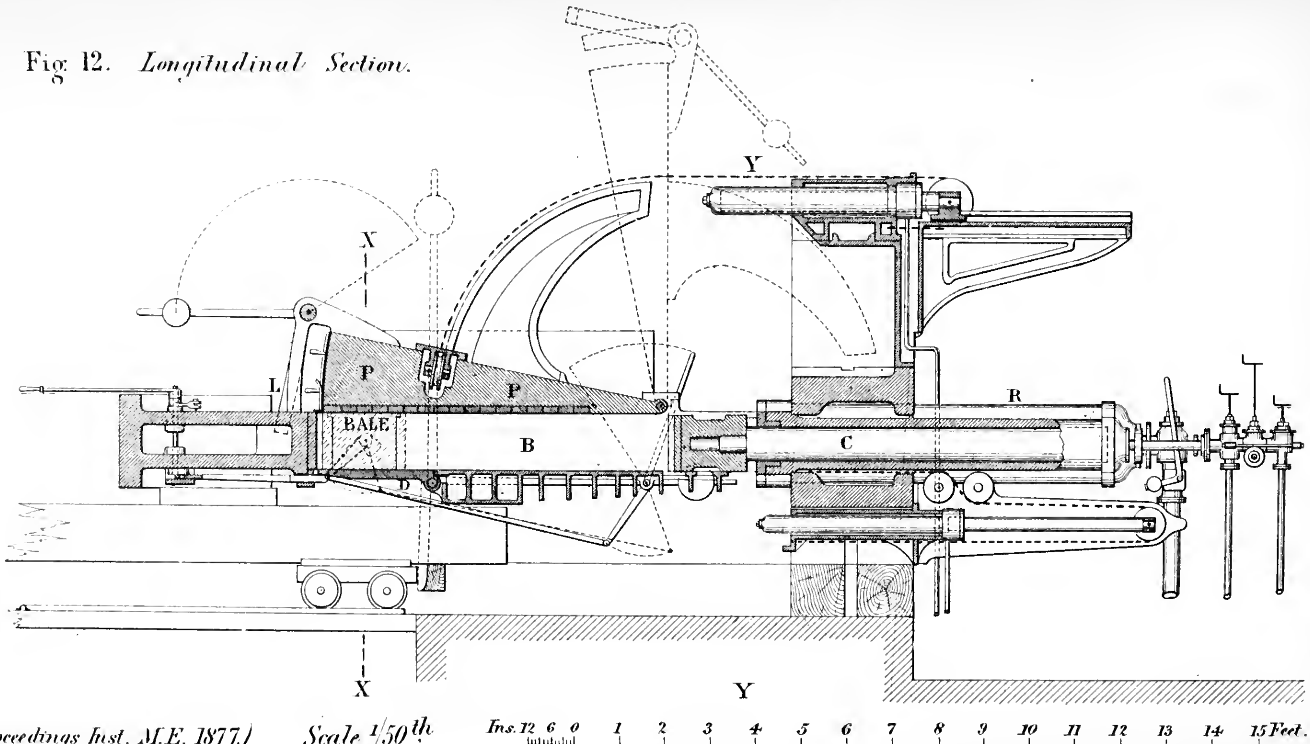
Scale 1/60th

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

HYDRAULIC PACKING PRESSES.

Wilson's Horizontal Press.

Fig. 12. *Longitudinal Section.*



(Proceedings Inst. M.E. 1877.) *Scale 1/50th.*

Plate 66.

HYDRAULIC PACKING PRESSES.

Wilson's Horizontal Press.

Fig. 13. *Transverse Section at XX.*

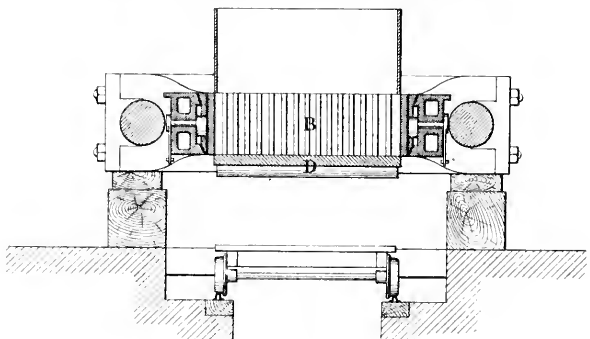


Fig. 14. *Transverse Section at YY.*

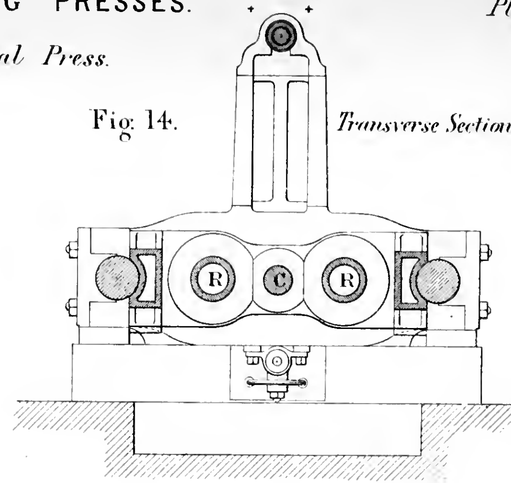
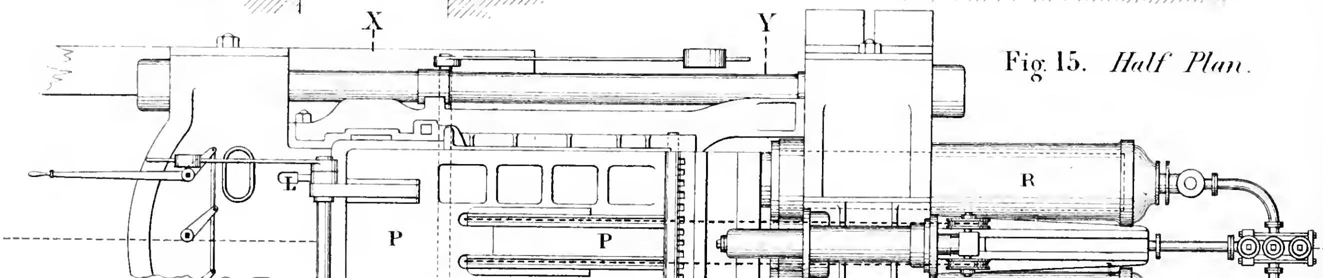


Fig. 15. *Half Plan.*



(Proceedings Inst. M.E. 1877.) *Scale 1/50th* Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Plate 67.

HYDRAULIC PACKING PRESSES. *Plate 68.*

Watson's Compound Vertical Press.

Fig. 16.

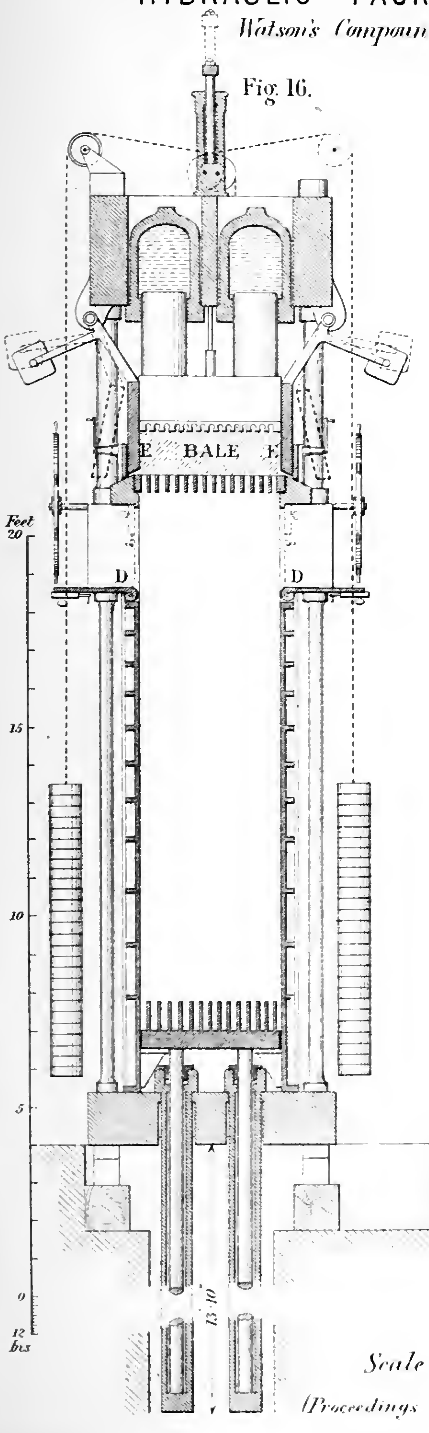
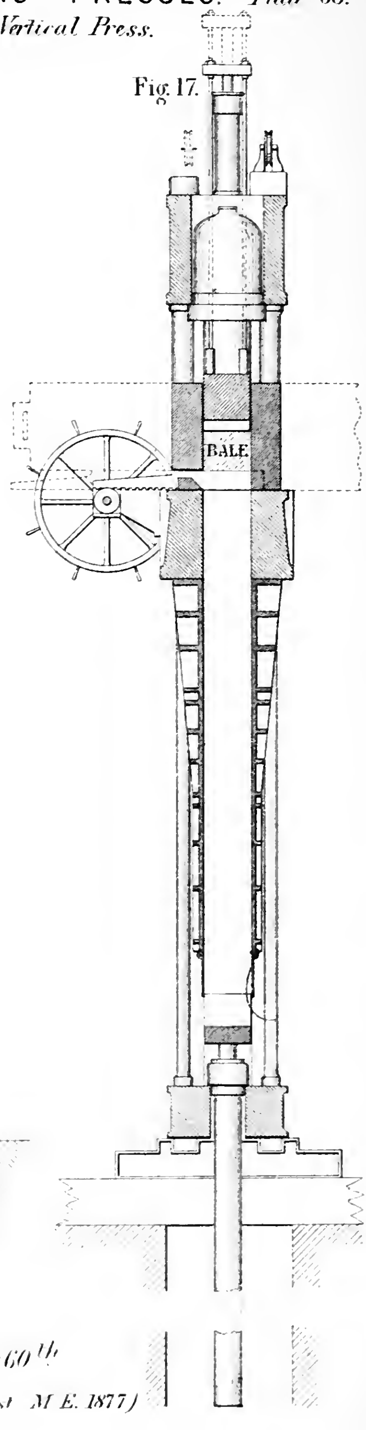


Fig. 17.

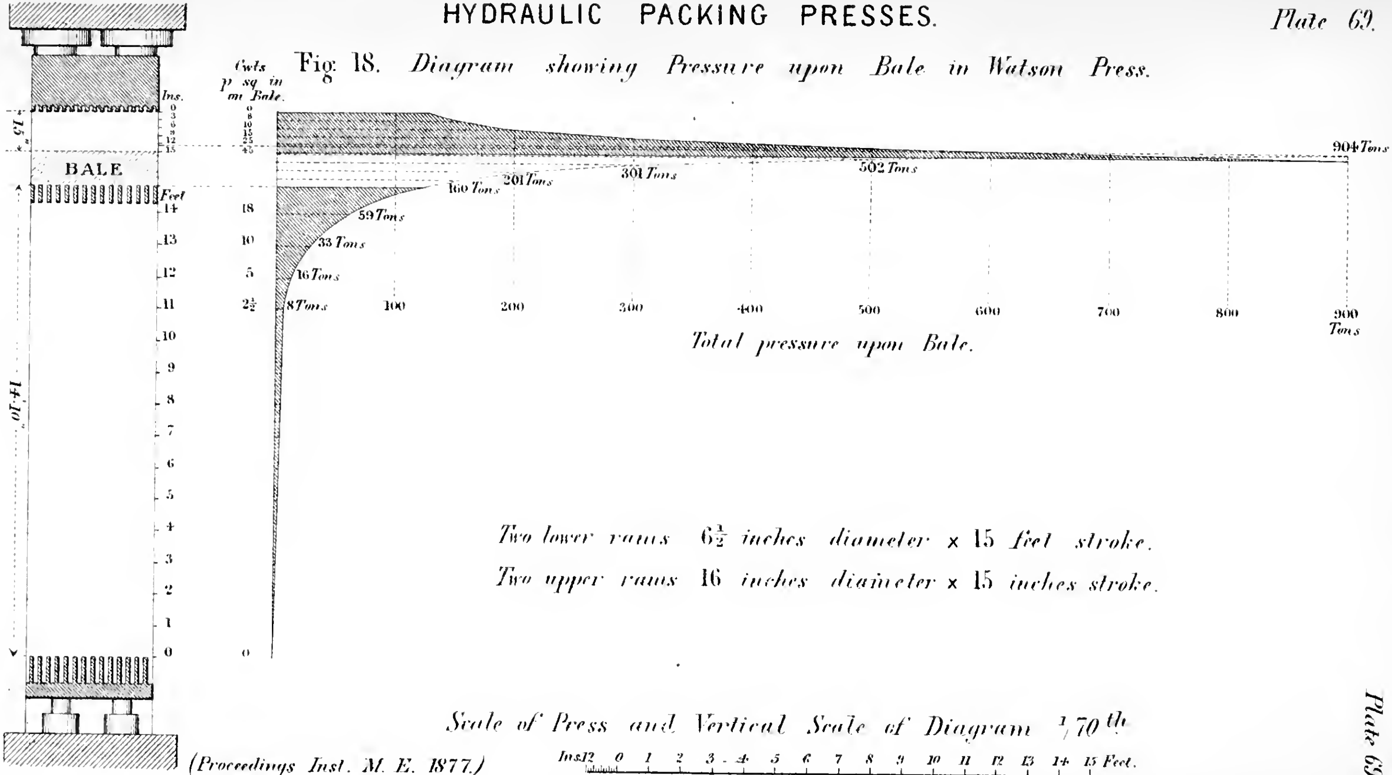


Scale 1/60th

(Proceedings Inst. M. E. 1877)

HYDRAULIC PACKING PRESSES.

Fig. 18. *Diagram showing Pressure upon Bale in Watson Press.*



Two lower rams $6\frac{1}{2}$ inches diameter × 15 feet stroke.

Two upper rams 16 inches diameter × 15 inches stroke.

Scale of Press and Vertical Scale of Diagram $^1/_{70}$th.

(Proceedings Inst. M. E. 1877.)

Plate 69.

Full-size Sections of Cup-Leathers.

Fig. 19.
Packing of Rams in Fig. 6.

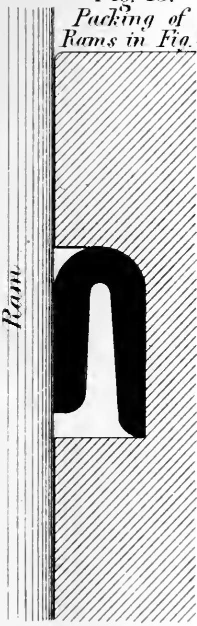


Fig. 20.
Packing of Top Rams in Fig. 8.

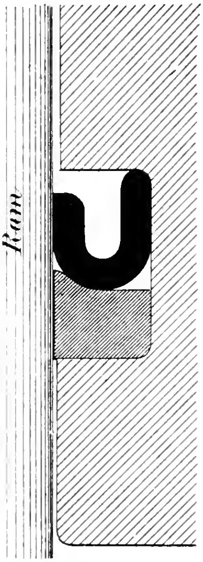


Fig. 21.

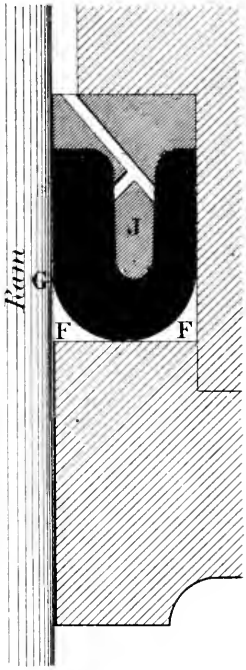


Fig. 22.

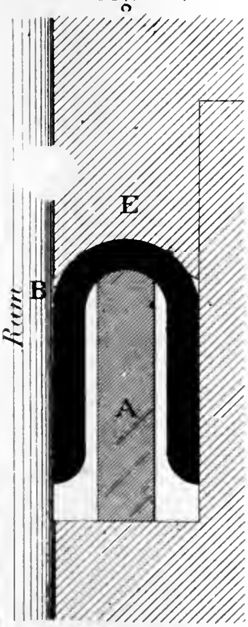


Fig. 23.

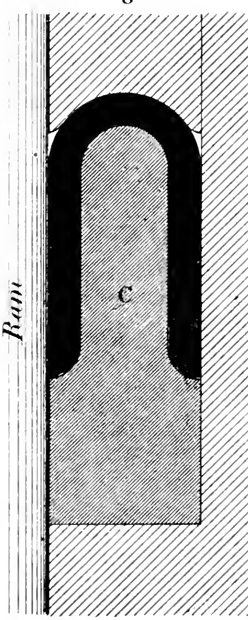


Fig. 24.
Scale 1/6th